DEC 26 '46 L

Volume 16 DECEMBER, 1946 Number 3

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

« CONTENTS »

Comparative Rates of Weathering of Some Common Heavy Minerals ..... *Lincoln Dryden and Clarissa Dryden* 91

Suspended Sediment Program of the Rock Island Office, Corps of Engineers, U. S. Army ..... *Troy L. Péwé* 97

The Correlation of Sediментary Rocks by Fossil Spores and Pollen ..... *L. R. Wilson* 110

Sediments from Alaskite, Capitan Mountain, New Mexico ..... *Raymond Sidwell* 121

A Color-Numerical System as Applied to Well Logs ..... *D. C. Maddox* 124

ANNOUNCEMENT

Geology as a Profession 129

REVIEWS

C. E. ZoBell. Marine Microbiology. *A Monograph on Hydrobacteriology* ..... *W. H. Twenhofel* 130

L. M. Fanning and Collaborators, 1945. *Our Oil Resources*.. ..... *W. H. Twenhofel* 130

C. S. Ross and S. B. Hendricks. *Minerals of the Montmorillonite Group, Their Origin and Relation to Soils and Clays*... ..... *W. H. Twenhofel* 131

Index 133

Journal of Sedimentary Petrology

W. H. TWENHOFEL, Editor
Madison, Wisconsin

Associate Editors

W. C. KRUMBEIN
Chicago, Illinois

K. O. EMERY
Los Angeles, California

HENRY B. MILNER
London, England

CLARENCE S. ROSS
Washington, D.C

R. DANA RUSSELL
University, Louisiana

The *Journal of Sedimentary Petrology* is published by the Society of Economic Paleontologists and Mineralogists, a division of The American Association of Petroleum Geologists. Numbers are issued in April, August and December.

The subscription price of the *Journal of Sedimentary Petrology* is $3.00 per year prepaid to addresses in the United States.

Single numbers, $1.50 each.

Postage is charged extra for all other countries: 40 cents on annual subscriptions (total $3.40).

The *Journal* will furnish reprints at cost. Orders should accompany corrected galley proof.

Communications about the *Journal*, subscriptions, rates, memberships, change of address, advertising and non-receipt of preceding numbers should be addressed to Society of Economic Paleontologists and Mineralogists, P.O. Box 979, Tulsa, Oklahoma. Claims for non-receipt of preceding numbers must be sent in within three months of the date of publication in order to be filled gratis.

Communications in regard to manuscripts or purely editorial matters should be addressed to W. H. Twenhofel, Editor, University of Wisconsin, Madison, Wisconsin.

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN, U.S.A.

Volume 16 DECEMBER, 1946 Number 3

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

CONTENTS

Comparative Rates of Weathering of Some Common Heavy Minerals ..... *Lincoln Dryden and Clarissa Dryden* 91

Suspended Sediment Program of the Rock Island Office, Corps of Engineers, U. S. Army ..... *Troy L. Péwé* 97

The Correlation of Sedimentary Rocks by Fossil Spores and Pollen ..... *L. R. Wilson* 110

Sediments from Alaskite, Capitan Mountain, New Mexico ..... *Raymond Sidwell* 121

A Color-Numerical System as Applied to Well Logs ..... *D. C. Maddox* 124

ANNOUNCEMENT

Geology as a Profession 129

REVIEWS

C. E. ZoBell. *Marine Microbiology. A Monograph on Hydrobacteriology* ..... *W. H. Twenhofel* 130

L. M. Fanning and Collaborators, 1945. *Our Oil Resources* ..... *W. H. Twenhofel* 130

C. S. Ross and S. B. Hendricks. *Minerals of the Montmorillonite Group, Their Origin and Relation to Soils and Clays* ..... *W. H. Twenhofel* 131

Index 133

NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal,* should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 16, NO. 3, PP. 91–96
FIG. 1, DECEMBER, 1946

COMPARATIVE RATES OF WEATHERING OF SOME COMMON HEAVY MINERALS

LINCOLN DRYDEN AND CLARISSA DRYDEN
Bryn Mawr College

ABSTRACT

When heavy minerals are liberated by weathering of their parent rock, resistant species show relative concentration and less resistant species decrease in relative abundance or disappear completely. The change in relative abundance of the various minerals from fresh rock to the weathered products is a measure of their comparative resistance to weathering.

Samples of fresh and weathered Wissahickon schist from Pennsylvania and Maryland were analyzed in this way. Zircon proved to be the most resistant mineral considered, garnet the most readily destroyed in weathering. Other common heavy minerals show considerable range in resistance.

The results of this study, particularly the data on weathering of garnet, were used in interpreting the origin of nearby Lower Cretaceous sediments. Applications of the method and results to other fields of geology and to soil science are suggested.

INTRODUCTION

The derivation of detrital heavy minerals is one of the few lines of evidence that bear on the source of the materials in sediments and sedimentary rocks. If certain minerals can have been derived from only one or a few source rocks, their presence in a sediment is a clue to the kinds of rocks being eroded, and to the direction of transport at the time the sediment was formed. Such simple and straightforward interpretation has little value, however, unless based on a considerable body of supporting data. Finding the same heavy minerals in a sediment and a nearby crystalline rock does not prove that the latter was the source rock unless all other reasonably likely sources have been ruled out.

The absence of available heavy minerals may be just as significant as their presence, though often more difficult to explain. A typical case of this kind (to be treated later in more detail) presents the following problem: a crystalline rock is the only known source for a number of distinctive heavy minerals; nearby, a younger sedimentary rock contains most of these minerals, but one or more of them are missing in the sediment. In some instances, the absence of available species cannot be explained; in others, it can be ascribed to destruction during transport, failure to be deposited in a sediment of a particular grain size, or to post-depositional disappearance.

A fourth possibility has been recognized: that the species in question were destroyed in the weathering of the crystalline rock, and were never made available for transport and deposition. However, there are very few published data on this aspect of the problem of non-appearance of available heavy minerals. The writers hope that the present paper will direct attention to this neglected phase of heavy mineral studies.

METHOD AND RESULTS

Most of the crystalline rocks of Pennsylvania and Maryland are covered by their own weathered products, and these weathered products furnish a very large proportion of the material now being carried by streams and deposited as recent sediments. The heavy minerals to be expected in these sediments—or in older sediments of the same area—are those species which have withstood the weathering of the rock which enclosed

them. The relative abundance of the different heavy minerals in the fresh crystalline rock, and in its weathered products, is a direct measure of comparative weathering rates of these minerals.

Samples must be carefully chosen if the method is to have any value. The two conditions that must be fulfilled are (a) that the weathered products are *in situ*, and (b), in the case of non-homogeneous crystalline rocks, that the weathered products have been derived from the same rock type as that of the fresh rock sample. For example, it would be difficult to collect significant samples at a locality where a banded crystalline rock outcrops on a steep hillside, unless no more than a "weathered crust" and a fresh sample are taken from one particular band. At the other extreme, especially trustworthy samples can be collected at a hilltop exposure of a homogeneous crystalline rock.

Samples of fresh Wissahickon schist and of its weathered products were collected at 14 localities in southeastern Pennsylvania and northern Maryland.* Consolidated rocks were crushed with mortar and pestle until they yielded a sufficiently large sample passing the ½ mm. sieve and retained on the ¼ mm. sieve; unconsolidated material was quartered and sieved directly. In both cases, the material on the ¼ mm. sieve was separated in bromoform (sp. gr. about 2.9), the light fraction was discarded, and the heavy fraction mounted in Canada balsam.

Grain counts of selected heavy minerals present in each sample are given in figure 1. For any one locality the same total grain count is shown for the fresh rock sample and for each of the samples of weathered material. This has been done to emphasize the *ratios* between the numbers of different mineral grains present and to make it possible to see, at a glance, how these ratios change in weathering. For example, at the first locality, in a total of some 140 grains, the ratio of garnet to zircon is about 135:5 in the fresh rock and about 15:125 in the weathered material; at locality 6 the ratios for garnet and staurolite are 75:25 and 50:50, in fresh rock and weathered material, respectively.

The histograms from all 14 localities show that garnet weathers *in situ* more readily and completely than any of the other species counted. In the fresh rock it is commonly clear, with sharp crystal faces or fractures; in the weathered products it shows much pitting and etching, becomes rounded and significantly smaller, and may disappear entirely. (The hypersthene of locality 5 is the only exception; if one sub-soil sample can be trusted, hypersthene disappears "rapidly" after having been initially concentrated with respect to garnet.)

In addition to this conclusion on the weathering of garnet, the histograms show comparative weathering rates of the various mineral species considered; several specific instances are worth mention. (1) Relative to garnet, zircon is concentrated more in weathering than any other species. This result bears out the general impression, imparted by the ubiquity of this mineral in sediments, that it is extremely resistant not only to abrasion but to weathering. (2) Somewhat surprising is the result that (green) hornblende is more resistant than garnet. Edelman and Doeglas (1932) have described features which indicate to them the "rapid" weathering of this mineral; the data presented here do not confirm their results. However, hornblende is rare in nearby, younger sediments, and it may break down rapidly in transport. (3) Staurolite is of intermediate resistance. Some grains in the

* The writers are unable to give an accurate definition of the weathered products, but the following descriptions may help the reader to visualize them: "Weathered rock" still retains its structure intact, but is often weak enough to crumble readily under a hammer blow. "Sub-soil" is rotten rock, that can be readily dug with pick or shovel; it is probably the "C-horizon" and in some cases perhaps the lower "B-horizon" of pedologists. "Soil" is material taken from around the roots of grasses and small plants; it probably corresponds in large part to the "A-horizon" and upper "B-horizon" of pedologists.

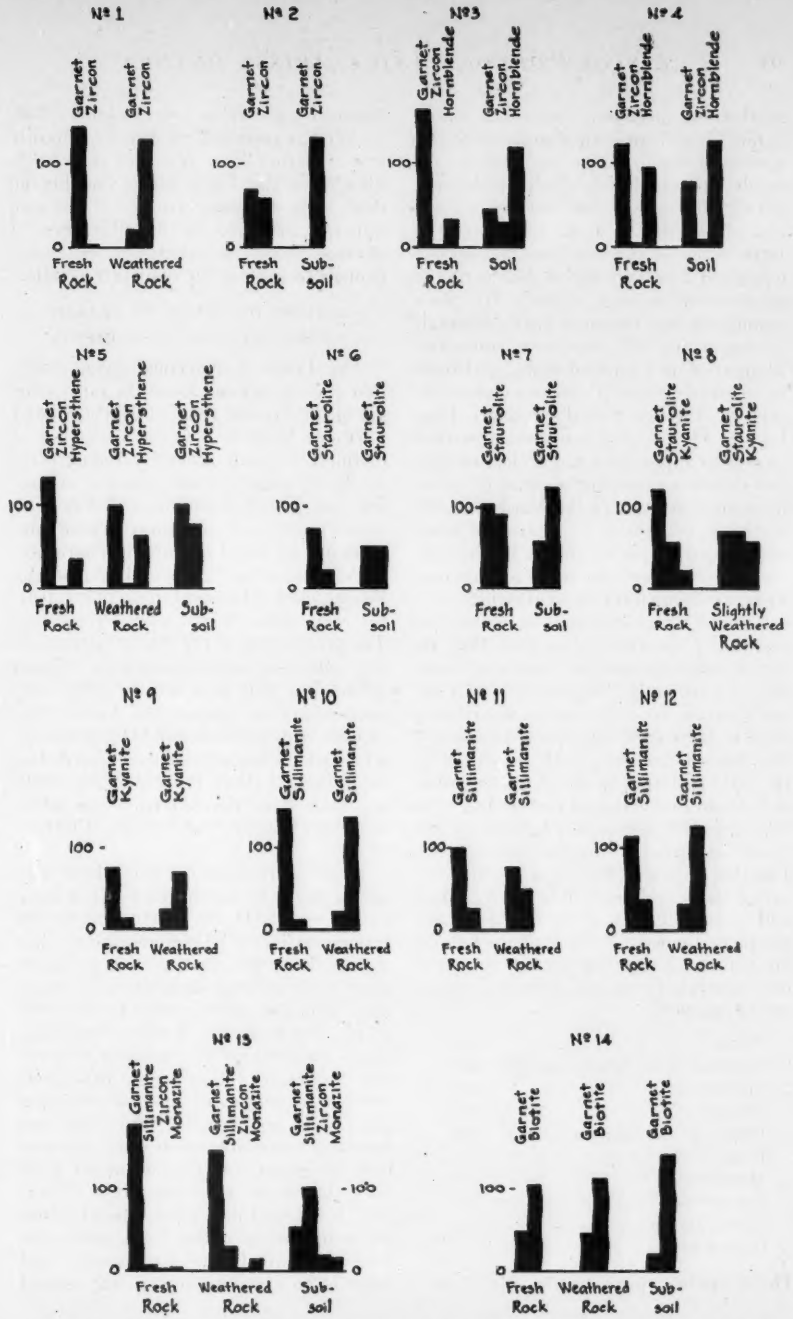


FIG. 1.—Changes in heavy mineral frequencies from fresh rock to weathered products. Numbers above the histograms are localities; the number at the side indicates the height of a histogram block representing 100 grains.

weathered products appear "moth-eaten," but there is an abundance of this species in nearby sediments. Perhaps the results presented underrate its resistance. (4) Kyanite is more resistant than garnet, and sillimanite is much more so. The latter is one of the most resistant species examined, but its probable destruction in transportation may explain its place among the less common heavy minerals in sediments. (5) Biotite is ordinarily thought of as a mineral easily destroyed in weathering, but it shows a concentration in the weathered products from locality 14. There is, however, a marked change in appearance and optical properties during weathering, so that it is perhaps incorrect to call the biotite in both the fresh rock and in its weathered products the same species. (6) On the basis of one series of samples, monazite appears to be quite resistant to weathering.

Though the grain counts of figure 1 are essentially qualitative, in that they do not measure changes in volume or mass, they are probably sufficient for a first approximation to comparative weathering rates of these common heavy minerals of the Wissahickon schist. If, for example, the ratio of garnet to zircon in fresh rock is 5:1 and in weathered rock is 1:5, it is assumed that zircon is 25 times as resistant as garnet. Using the data of figure 1 in this way, and making a rough average of the results from different localities and from different kinds of weathered products, the writers obtained the following values for the resistance of the various minerals compared with the resistance of garnet:

Zircon	100
Tourmaline (no figures available)	80?
Sillimanite	40
Monazite	40
Chloritoid (no figures available)	20?
Kyanite	7
Hornblende	5
Staurolite	3
Garnet (taken as:)	1
Hypersthene	<1?

These figures apply to the Maryland-Pennsylvania region only. Goldich (1938, p. 52) has reported an exactly opposite result (garnet more resistant than hornblende) in the Black Hills. Possibly he dealt with different varieties of the two minerals, or it may be that differences of climate, slope, or vegetation are great enough to explain the disparate results.

BEARING ON ORIGIN OF CERTAIN LOWER CRETACEOUS SEDIMENTS

The Lower Cretaceous clays, sands, and gravels exposed along the inner margin of the Coastal Plain of Maryland and northern Virginia contain a number of distinctive heavy minerals. Among them are large, angular, fresh grains of staurolite and pink tourmaline, and less common kyanite and sillimanite. These minerals are identical in varietal characters with the same species found in the nearby Wissahickon schist and in no other nearby rock older than Lower Cretaceous. The provenance of the heavy minerals in the sediment, then, appears to be well established. But although the schist contains abundant garnet, the Lower Cretaceous sediments contain little or none—a fact which the writers once regarded as an indication that the sediments could not have been derived from the schist (Dryden, Lincoln, and Dryden, Clarissa, 1938).

The absence of garnet from these sediments might be accounted for in a number of ways: (1) By destruction during transportation. Experimentation has shown, however, that garnet possesses more than average durability in transport, and the other species in the sediments show little sign of wear or rounding. (2) Consideration of "grading factors" and "hydraulic values" might explain its absence in sediments of some particular grain size, but samples from silts and from fine and coarse sands show the same lack of garnet. (3) Garnet might have been destroyed after deposition. However, it is found in the same area in similar sedimentary rocks, both older and younger than Lower Cretaceous, and there is no apparent reason why garnet

should have disappeared from rocks of this one age alone. Therefore, though the factors enumerated above may be contributory, the writers believe that any one or any combination of them is insufficient to explain the absence of garnet in the Lower Cretaceous sediments.

The only sufficient explanation known to the writers is weathering of a large proportion of the garnet *in situ* in the schist, so that little was made available for transport and deposition during Lower Cretaceous time. The histograms of figure 1 show that garnet is not being completely destroyed in the "present" weathering cycle, and all local streams carry significant quantities of this species. It must be assumed, therefore, that the conditions during Lower Cretaceous time were different from those of the present. Perhaps the climatic and physiographic conditions were somewhat like those of the southern Piedmont of today. In this area, reconnaissance studies indicate that the fresh rocks contain usual quantities of garnet, but the weathered products are deficient in this respect. The streams carry but little garnet, as shown by the small percentages reported by Stow (1939) for the sediments of the James River and by Martens (1935) for the coastal sands derived from the southern Piedmont. In any case, no incredibly long or rigorous weathering is required to explain the lack of garnet in the Lower Cretaceous sediments of Maryland and northern Virginia.

OTHER APPLICATIONS

This method of analysis can be put to a number of uses; a few of the more obvious ones will be mentioned. (1) Certain mineral species are concentrated in the weathered products. For example, fresh Wissahickon schist contains only scattered and rare zircon, but this mineral is common in the overlying soils. Chloritoid behaves similarly, although it is not concentrated to the same degree. In general, rare species resistant to weathering may be found more easily in the weathered products than in the fresh parent rock. (2) In determining the character of the bedrock by study of its overlying soil—as in the work of Dorothy Carroll (1936–17, 1939)—mineral destruction and concentration during weathering must be taken into account. (3) A very similar method is being used by pedologists, with promise of important uses in problems of soil genesis (Cady 1940; Jeffries and White 1940; Marshal 1940; Marshall and Haseman 1942). Pedologists may be expected to furnish valuable data on the effects of soil moisture, slope, drainage, and of vegetation types on weathering of heavy minerals. (4) Finally, the method gives comparative and relative weathering rates for different heavy mineral species. Once these rates have been determined for the important mineral species and varieties, for different climatic and physiographic conditions, reliable interpretations of past conditions will be possible.

REFERENCES

CADY, JOHN G. *1940*. Soil analyses significant in forest soils investigations and methods of determination: 3. Some mineralogical characteristics of Podzol and Brown Podzolic forest soil profiles: *Soil Sci. Soc. Am. Proc.*, vol. 5, pp. 352—354.

CARROLL, DOROTHY. *1936–37*. Some aspects of soil mineralogy: *Roy. Soc. W. Australia*, Jour., vol. 23, pp. 7–12.

———. *1939*. Sand-plain soils from the Yilgarn Goldfield: *Geol. Surv. of W. Australia*, Bull. 97, pp. 161–180.

DRYDEN, LINCOLN and DRYDEN, CLARISSA. *1938*. Stratigraphic importance of heavy mineral studies in the Philadelphia region: *Penna. Acad. Sci., Proc.*, vol. 12, pp. 101, 102.

EDELMAN, C. H. and DOEGLAS, D. J. *1932*. Relikstrukturen detritischer Pyroxene und Amphibole: *Miner. und Petrog. Mitt.*, Bd. 42, pp. 482–490.

GOLDICH, SAMUEL S. *1938*. A study in rock weathering: *Jour. Geology*, vol. 46, pp. 17–58.

JEFFRIES, C. D. and WHITE, J. W. *1940*. Some mineralogical characteristics of limestone soils of different localities: *Soil Sci. Soc. Am., Proc.*, vol. 5, pp. 304–308.

MARSHALL, C. A. *1940.* A petrographic method for the study of soil formation: *Soil Sci. Soc. Am., Proc.*, vol. 5, pp. 100–103.

——— and HASEMAN, J. F. *1942.* The quantitative evaluation of soil formation and development by heavy mineral studies: *Soil Sci. Soc. Am., Proc.*, vol. 7, pp. 448–453.

MARTENS, JAMES H. C. *1935.* Beach sands between Charleston, South Carolina, and Miami, Florida: *Geol. Soc. America*, Bull. 46, pp. 1584, 1593.

STOW, MARCELLUS H. *1939.* Reflection of provenance in heavy minerals of James River, Virginia: *Jour. Sed. Petrology*, vol. 9, pp. 86–91.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 16, NO. 3, PP. 97–109
FIGS. 1–6, DECEMBER, 1946

SUSPENDED SEDIMENT PROGRAM OF THE ROCK ISLAND OFFICE, CORPS OF ENGINEERS, U. S. ARMY

TROY L. PÉWÉ
Stanford University, California

ABSTRACT

The Rock Island Office, Corps of Engineers, U. S. Army has since 1940 carried on an extensive study of the suspended sediment of many streams which lie in its district. The district embraces parts of Iowa, Illinois, Wisconsin and Missouri and has its main office in Rock Island, Illinois.

In 1938 an ingenious sampler was developed but it proved too complicated for widespread use and it was never utilized at any permanent station. The Rock Island Simplified Time-Integrating Sampler was developed in 1939 and is still used today on some of the stations. Constant study during the last five years has resulted in the improvement of this model.

The depth-integrating method of sampling is used and samples are taken at least once a day at thalweg. The samples are shipped to the central laboratory at Rock Island, Illinois where they are analyzed for total sediment content. Some of the samples are analyzed for size grade distribution of the sediment by using the decantation method.

The development of this sediment program has made available many data for use in connection with various engineering projects within the district.

INTRODUCTION

The following is a brief review of the history and progress of the suspended sediment measurement program of the Rock Island Office, Corps of Engineers, U. S. Army.

Although available records of suspended sediment measurement go back as far as two centuries, intensive, scientific, cooperative interest in this science is relatively recent. By 1900, reports of suspended sediment measurements are found for many streams in various countries including the United States, Germany, India, and France; however, in all cases there was much experimentation as to where, how, and when the sample should be taken in the stream. The first record of sampling in the United States was probably that done on the Mississippi River in 1838 by Captain Talcott of the U. S. Army (1).

In this instance, as in many of the earlier records, no mention was made of the sampling method used. Before the beginning of the Twentieth Century many attempts had been made at suspended sediment measurement in the United States by public and private agencies, including the U. S. Geological Survey, the U. S. Engineer Department, and the Interstate Water Commission.

In the last thirty years much progress has been made, and many public and private agencies are doing research in suspended sediment measurement today.

The suspended sediment which is the center of attraction of this research is only one of the ways by which sediment is transported by streams. The geological position of the stream is to transport material to the sea; this material is transported in various ways, the most important of which is probably suspended sediment. Suspended sediment is sediment which remains in suspension in water for a long period of time without touching the bottom (1, p. 109). Some material is transported as bed load, that is the moving sediment which is in contact with the bottom at practically all times, being moved by the force of the water. In addition, some material is carried as dis-

solved solids. All of these comprise the stream load.

The study of suspended sediment has great economic value as the sediment "presents problems of vital importance in many projects for flood control, soil conservation, irrigation, navigation and water power development. Costly maintenance, loss of efficiency and in many cases complete destruction of important engineering works have been experienced due to filling of reservoirs by sediment, filling or scouring in navigation channels, and erosion and gullying on arable lands" (1).

Many agencies are vitally interested in suspended sediment measurement. Some of which are (1) Corps of Engineers, U. S. Army, (2) U. S. Geological Survey, (3) Soil Conservation Service, Department of Agriculture, (4) U. S. Bureau of Reclamation, (5) Tennessee Valley Authority, (6) Indian Service, (7) Flood Control Coordinating Committee of the U. S. Department of Agriculture, (8) Interstate Water Commission, (9) Mississippi River Commission, (10) Individual hydraulic and geologic departments of many universities including the Iowa Institute of Hydraulic Research at Iowa City, (11) and many private engineering concerns.

GENERAL STATEMENT

Suspended sediment investigations were carried on by the Rock Island Office prior to 1940; but it was not until that year that sampling stations were established on various streams within the district where it was apparent that the sediment load of the streams would affect the design, operation, or useful life of a proposed improvement.

The discussion considers the problems encountered in the search for a simple portable, low cost sampler which was to be used in extensive work on many streams and yet yield reliable results. Advancements made in other phases of the program are reviewed.

The Sampler

In 1938 the Rock Island Office made preparations to enter the field of suspended sediment study by the development of the ingenious sediment sampler now termed the Early Rock Island Sampler (fig. 1). This device was a time-integrating sampler, the basic principle of which was to secure over a period of time

FIG. 1.—The 1938 Time-Integrating Sampler of the Rock Island Office, Corps of Engineers, U. S. Army. Mechanism is housed in the upper portion. Sediment container attached below. Suspended on standard current meter carriage.

a sample respresentative of the average sediment conditions. Another name applied to this type of sampler would be a point sampler.

This sampler consisted of a streamlined body 18 inches long which housed the operating mechanism and a streamlined container attached immediately below. A conduit with a trapezoidal cross-section extended longitudinally through the

streamlined mechanism portion. Since the cross-section area of the water conduit was more than three square inches, and since the conduit was only 18 inches long, substantially natural stream velocities passed through it. A series of small instantaneous samples were collected from the relatively undisturbed flow within the conduit by turning a valve plug of the stop cock type which is actually a section of the conduit, and has the same cross-section. This valve, when turned 90° traps a portion of the water in the conduit and drops it into the container below. The valve was turned by a heavy manually wound spring when an electric current, controlled by the operator, sets off the trigger mechanism. The procedure was able to be repeated seven to ten times on one winding of the valve spring. A small electric motor returned the valve to a non-collecting position. A signal light on the surface informed the operator of the position of the valve.

The sampler proved too complicated for widespread use throughout the district by untrained resident collectors; therefore, it was never utilized at any permanent station.

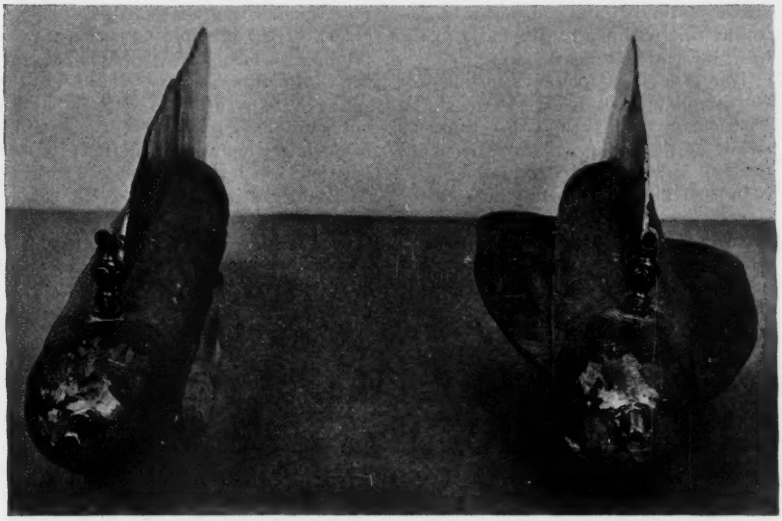


FIG. 2.—Front view of the Rock Island Depth Integrating Sampler. Right: sampler with horizontal fins. Left: sampler with horizontal fins removed. (Note: The controlled exhaust vent on the top side of the sampler, points downstream in actual operation, or 180° from the position in the above illustration.)

In an attmpt to develop a simple sediment sampler there was built in 1939 the Rock Island Simplified Time-Integrating Sampler, a modification of which is still used today on some stations. As shown in figure 2, the sampler consisted of a horizontal sample container with an intake nozzle at one end and a removable tail fin at the other for the extracting of the collected sample. A controlled air exhaust vent extended upward, the opening of which pointed downstream. Brass horizontal and vertical fins were attached to the lead covered body and extended almost the entire length of the sampler.

The sample entered in the intake opening which was ¼ inch brass tube flush at the upstream end of the streamlined sample container and faced directly into the stream flow. The capacity of the sampler was about 600 cc.

The sampler was used in a depth-integration method of sampling, that is, it was lowered to the bottom of the stream and raised at a constant rate, collecting the sample continuously while being lowered and raised.

This type of sampler was installed at 19 sampling stations throughout the District in 1940–41 and a continuous record of the sediment load carried by these streams was initiated.

In 1939 there was initiated the greatest cooperative investigation into the study of methods used in measurements and analysis of sediment loads in streams that had ever been held up to that time. This project was carried on at the hydraulic laboratory of the State University of Iowa through the cooperation of seven federal governmental and one state agencies; namely, the U. S. Engineer Department, the U. S. Geological Survey, the U. S. Bureau of Reclamation, the Flood Control Coordinating Committee of the Department of Agriculture, the Tennessee Valley Authority, the Office of Indian Affairs, and the Iowa Institute of Hydraulic Research. This investigation, as stated in 1939, has as its objectives the review of existing equipment and practices; conducting laboratory tests on such equipment and practices; and the development of improved equipment and more standardized methods.

In the course of this study the Rock Island Sampler was carefully tested and improvements suggested. In December 1941, some of the tests were published (2) and it was revealed that a discrepancy in sediment collection was created by having a blunt nose intake, that is, the intake flush with the front of the sampler. Exhaustive tests showed that, "The blunt nose intake—collected 12% excess of sediment at normal intake rate." With this knowledge available, a one inch nozzle extension was initiated and then the effect of the nose of the sampler upon the suspended sediment was relatively negligible.

With the beginning of sampling in 1942, all of the stations were equipped with samplers with the one inch nozzle extension. All figures compiled previously from samples taken with the blunt nose sampler were corrected.

One of the greatest advancements in the improvement of the sampler was incorporated in the summer of 1943. In the spring of that year it was noticed that the horizontal fins (fig. 2) caused the sampler to deviate from a horizontal position, a position which is necessary if a true depth-integrating sampler is to be obtained. If the sampler is tilted downward, air is trapped in the back end of the sampler chamber and cannot escape. The sampler may fill until water is passing through and out the air exhaust, yet the volume of the sample collected will not indicate that the sampler was entirely filled. With this excess amount of water passing through the sampler, higher sediment concentrations will be recorded. Also, if the sampler is tilted downward it may dive into the bed load. Most of the times bed load in the sample can be noticed and the sample can be discarded; however, many times it slips by unnoticed and the concentration recorded is in error.

To determine the percentage of error developed in this manner a series of tests were conducted. The following is the data recorded: (The sediment content is analyzed in parts per million).

Comparison at Dubuque, Iowa
(Mississippi River)

	May 12, 1943		May 18, 1943	
Size mm.	With Fins	Without	With Fins	Without
.005	14.3	16.9	26.9	26.7
.0125	11.3	5.1	25.3	17.0
.030	13.9	5.8	14.5	13.2
.074	10.6	1.9	12.3	10.8
over .074	59.5	2.3	13.6	7.9
Total p.p.m.	109.6	32.0	92.6	75.6

Comparison at DeWitt, Iowa
(Wapsipinicon River)

Size mm.	May 12, 1943 With Fins	May 12, 1943 Without	May 18, 1943 With Fins	May 18, 1943 Without
.005	21.2	17.6	165.8	176.8
.0125	15.7	8.2	249.8	196.6
.030	27.0	20.4	187.0	189.5
.074	32.3	23.2	196.2	206.4
over .074	85.9	37.4	186.5	195.0
Total p.p.m.	182.1	106.8	985.3	964.3

In the above tests the samplers were lowered and raised at a constant rate with a reel and steel cable.

A comparison between the Rock Island samplers with and without horizontal fins was executed in 1944 as a check on the 1943 tests. The samples were taken from the Mississippi River at Rock Island, Illinois. In this experiment, conducted by highly trained personnel, the sampler was lowered only 15 feet into the stream and did not traverse the entire depth. Ten samples were taken, five in succession with the sampler without the fins, and five in succession with the sampler with the horizontal fins. Each sample was collected at a constant rate as verified with a stop watch.

Comparison at Rock Island, Illinois
(Mississippi River)
August 11, 1944

With Fins	Total p.p.m.	Without	Total p.p.m.
Sample #6	52.4	Sample #1	45.3
Sample #7	43.5	Sample #2	29.7
Sample #8	40.8	Sample #3	43.4
Sample #9	49.3	Sample #4	36.2
Sample #10	48.6	Sample #5	35.8
Average p.p.m.	46.9		38.1

From these data it is evident that the unmodified sampler obtained concentrations in excess of the amount obtained by the modified sampler.

The Rock Island Sampler with the horizontal fins obtained higher concentrations than did the sampler developed at the cooperative investigation conducted at Iowa City, Iowa; but the Rock Island Sampler without the fins compared rather favorably to this standard.

After these data were reviewed, the horizontal fins were removed on all the samplers throughout the Rock Island District (fig. 2).

Although the modifications incorporated in the Rock Island Sampler in the last two years have considerably improved the sampler, unless the collecting of samples is carried on by a carefully trained observer, the sample may be in error. The fact which gives rise to this error is that the sampler has a non-removable sample container which can lose sediment when the sample is transferred to another container (fig. 3). The drawbacks of this non-removable container can be listed as follows:

(a) As found by laboratory investigations and other tests—"Even with intense shaking of the sampler as the sample is poured out, some of the fine sediment may adhere to the walls of the container and some coarse particles may fail to pour out" (2). It is easy to see that if some of the sediment remains in the sampler, that the sample is inaccurate and the next sample because of the residue in the sampler will also be inaccurate.

(b) Transfer of the sample from the sampler to the container is very seldom accomplished without spilling some of the sample. It is very difficult to shake the sampler intensely and then quickly dump the sample in the container before it has a chance to settle and still have all the sample enter the jar. Expertly trained observers can reduce this error to a minimum; however, resident observers may create a discrepancy by this operation.

Beginning in 1943 the Rock Island Office began to replace the modified Rock Island Sampler with a newly developed sampler, the product of the Joint Investigation conducted at Iowa City, Iowa. This is a sampler which has a removable sample container and none of the sample

is lost in transferring it to the laboratory. Because of war time conditions replacements have been slow, but it is hoped that all stations will be equipped with the new sampler in the near future. The details of the new sampler will be revealed in a future report of the Joint Investigation.

Field Stations

The samples are taken from permanent suspended sediment sampling stations, which are established on various streams depending upon the nature of the information desired. Physically the stations consist of a platform and reel erected on a bridge over the stream (fig. 4). The platform enables the collector to perform the operation without hazard from the passing traffic. The sampler is lowered and raised with a steel cable attached to the reel; with the use of the reel a constant rate can be maintained. Some of the earlier stations were not equipped with a reel, but during the last few years more reels have been erected. Only a few stations are not now functioning with a reel.

The position of the station on the bridge is such as to establish a vertical sampling position at thalweg or point of greatest depth or in the middle of the channel as in the case of large streams like the Mississippi. In such large streams more than one station or vertical should be used, but the Rock Island Office program has not yet advanced to the stage where multiple stations are utilized.

FIG. 3.—Extracting sample from modified Rock Island Sampler.

The practice of sampling the stream only at one point (that is, from top to bottom of the stream at only one place in the river) has a possibility of giving false report as the point chosen may not be representative of the whole stream cross-section in sediment concentration or stream discharge. Therefore, a cross-section of the stream's sediment concentration and discharge is obtained by

taking measurements and collecting samples every 10, 20, or 100 feet across the stream, depending upon its size. From this record the average sediment concentration of the stream at this cross-section is computed, and it is compared with the concentration obtained at the permanent sampling station. If this comparison shows that the concentration obtained at the sampling station is not representative

The method of the sampling in the vertical which has been in practice for five years is that of taking a depth-integration sample. That is, instead of collecting samples at various points in the vertical, a single sample is collected from all points in the vertical by lowering and raising the sampler at a constant rate. The method is relatively reliable under usual conditions and if the sampler

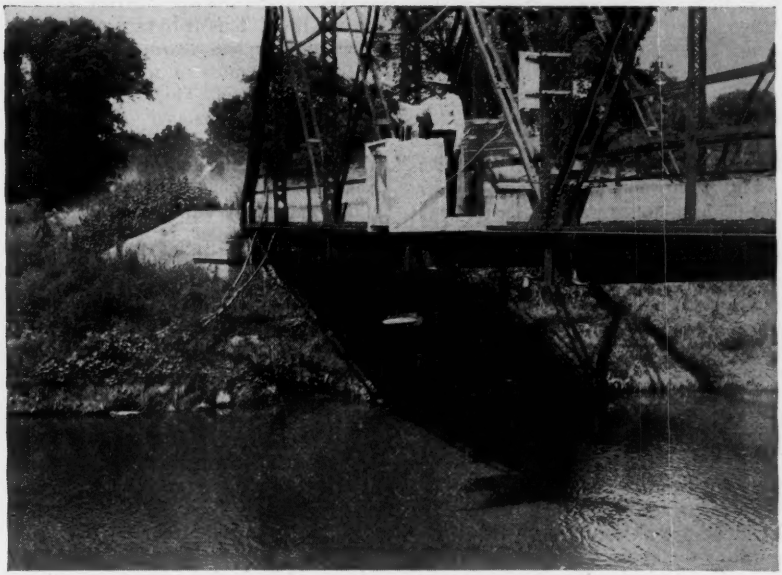


FIG. 4.—Suspended Sediment Sampling Station on the Galena River near Buncombe, Wisconsin. Showing platform, reel, and suspended sampler.

the station's figures must be modified or the position of the sampling station changed to another place on the bridge.

These cross-section readings of course must be made at various stages of the river and no true picture can be obtained until a series of readings have been accumulated. The Rock Island Office has this plan in operation, but not all streams have been sampled as yet in such a cross-section method.

can approach close to the bottom. The Rock Island Sampler can reach as close to the bottom as advisable, as the intake nozzle approaches within 1½ inches of the bottom. It also has the advantages of being simple, rapid and easy to use and well adapted to dependable observers, even though inexperienced. A great time and money saving feature is the fact that only one sample has to be taken on the vertical and therefore only one sample

has to be analyzed.

The frequency at which the samples are taken is perhaps the most important factor entering into the accuracy of determining the suspended sediment load carried by streams. The frequency is controlled almost entirely by the fluctuation of the sediment concentration. This fluctuation is of two types: One related to stream turbulence and the other controlled by the characteristics of the stream, watershed and rainfall. The time integrating type of samplers are an attempt to compensate for the momentary type of fluctuations. The long time fluctuation is the type which most governs the frequency of sampling.

In the early days of the Rock Island Office sediment program, sampling was controlled by stage alone and the frequency of sampling was low. Generally, it consisted of taking samples once a week at normal flows and once a day at high stages. At extreme flood conditions samples were collected three times a day. Great errors can be introduced on smaller streams and even on larger streams with such infrequent sampling. On many small streams, over 90% of the total yearly sediment load is discharged in a day or two (3).

By actual tests (3) it is noticed that the most important time of sampling and when frequency of sampling should be at its highest peak is during a rise. Inasmuch as the sediment discharge peak is generally reached before the water discharge peak, it is evident that the early part of the rise is by far the most important. After the crest has been reached the sediment concentration drops at a rather constant rate and the frequency of sampling can be lowered considerably. In fact, if the early part of the rise has been missed, frequent sampling later is rather unimportant.

In an attempt to evaluate the frequency of sampling, many actual cases were reviewed. One example in the Rock Island District that may be cited is that of Rock Creek at Morrison, Illinois. This small creek, with a watershed of 169 square miles, suffered heavy rains on June 2 and 3, 1941. Samples were taken many times during the day at various intervals. Fifteen samples were taken in three days and a fairly good record of the sediment load was obtained. However, had the practice of sampling only once a day at a definite time been in effect, it would have been possible that the figure obtained would have been76% in error.

Another example that may be considered is the Raccoon River at Van Meter, Iowa. This tributary to the Des Moines River has a watershed of 3,410 square miles, most of which is on the Kansan till plain. The only frequency schedule was controlled by the stage reading method which stated that samples should be taken once a week below a stage of 6 feet; once a day between stage of 6 feet and 11 feet and three times a day over 11 feet.

By this method it is possible for a rise of 5 feet carrying an enormous sediment discharge to sweep by and not be sampled at all because the stage did not reach 6 feet. Also, it is possible that a much more important and powerful rise of 5 feet may occur raising the stage from 6 to 11 feet and samples would be taken only once a day. The samples are as many times as not taken only on the falling side of the rise rather than on the important early part of the rise. A gage reading of 10 feet would be very important on the rising side, but a reading of 10 feet on the falling side would be far less important, yet the same frequency is applied on both cases under that method.

As the result of an investigation, the Office modified the frequency schedule with the following general plan:

A. Samples are taken daily at low flow.
B. When the stream rises slowly samples are taken three times a day.
C. When the stream rises at a very fast rate samples are taken hourly until the crest is reached.
D. After the crest is reached and the stage is falling, samples are taken again only once a day.

This plan is general and is modified for

each individual station; that is the definition of fast or normal flow or rise will vary according to the individual stream.

The schedule now followed on the Raccoon River at Van Meter, Iowa is as follows:

(1) Take samples daily at normal flow.
(2) When stream rises at rate of less than 2 feet in six hours take three samples daily.
(3) When stream rises at rate of 2 feet in six hours or faster, take samples hourly.
(4) After the crest of the rise has been reached, take samples daily.

On the Des Moines River, a much larger stream than the Raccoon, the following frequency is in effect at the station near Tracy, Iowa:

(1) Take samples daily at normal flow.
(2) When stream rises at the rate of less than 1 foot in six hours, take three samples per day.
(3) When stream rises at rate of 1 foot in six hours or faster, take samples hourly.
(4) After the crest of the rise has been reached, take samples daily.

These two stations are representative of most in the district.

The samples collected at the stations are of two sizes. Small samples of about 300 to 400 cc. are collected as standard practice; however, larger samples are collected for size grade analysis. The large samples are composite of four small samples being collected in succession and put in a gallon jar. Large samples for detailed analysis are taken every tenth sample in numerical order. In addition, large samples are taken daily on every rise until the crest is reached. Rises of less than a day in duration have only one large sample.

The Rock Island District uses resident observers to collect the samples and in most instances the same individual is the reader of the gage which records the height of the stream. The samples are stored near the station and approximately twice a month they are picked up throughout the district by truck which brings them to the central laboratory located at Rock Island, Illinois. Each jar or bottle has the following information placed on it by the collector: name of stream, number of sample, gage height, date, and the exact time at which the sample was taken.

Every sample taken is entered on a Sediment Sampling Report Card with the same data as appear on the sample bottle. This card is mailed to the central office where the laboratory report of the sample is added. There is a separate card for every sample; at least one card is mailed every day.

Laboratory Analysis

The laboratory for analysis of the suspended sediment samples is equipped to handle the many samples which are received daily, but post-war plans contain many improvements for the laboratory.

Upon being received at the laboratory, the large and small samples are separated and placed on tables. The procedure for analysis of the small samples is relatively simple and it will be discussed first. The following steps are noted:

(1) The jar with the field sample is weighed upon receiving it at the laboratory.
(2) It is then allowed to stand undisturbed for several days until the sediment has completely settled to the bottom.
(3) Next, the clear water is siphoned off without disturbing the sediment. This surplus water is discarded.
(4) The remaining water and sediment is washed with distilled water into evaporating dishes, which are then placed in the drying oven at 110°C. and allowed to dry.
(5) They are then removed from the oven and placed in the desiccator until cool.
(6) When cool, the evaporating dishes with the contained sediment are weighed on the analytical balance to 0.0001 gram.
(7) The known weight of the dish is subtracted from the total weight to

obtain the weight of the sediment.

(8) The clean empty field jar is weighed and its weight subtracted from the original weight of the sample and the jar as obtained in step No. 1.

(9) When the weight of the original sample is known and the weight of the sediment in the original sample is also known, the parts per million content can be calculated.

The large samples received by the laboratory are not only analyzed for their total sediment content but are also analyzed for the percentage of sediment of various sizes. The decantation method is used in this fine-grained analysis.

"In the decantation method the sediment is dispersed uniformly throughout the sedimentation medium and then, after a certain period of time, the liquid is decanted to a certain depth. All particles with a fall velocity exceeding a certain value will have settled past the elevation of decantation and will remain in the settling tube" (2). Stoke's fall velocity law is used to determine the time required for particles of the limiting sizes to reach the withdrawal elevation and this time period is modified depending upon the temperature, of the medium.

This method is used because it is the least expensive from the standpoint of laboratory equipment; as no special equipment other than that available in an ordinary laboratory is required. It is also accurate and reliable if conducted with care, and is relatively simple once the routine is established. It is true, however, that the method is laborious and time consuming if accurate results are to be obtained.

Many types of withdrawal methods have been tried by various agencies (2) in the last 50 years, but probably the most simple and most widespread is the use of the ordinary siphon. The Rock Island Office has used the siphon in its sediment analysis since 1939; however, studies are underway for the introduction of a modification of this withdrawal method. At present the siphon is still used.

DESCRIPTION OF PROCEDURE FOR SIZE GRADE ANALYSIS

General

The cylinders used for settling are 39 cm. in length and 7 cm. in diameter. The distance from the top to the withdrawal point is 32 cm. The glass siphon tubes are ¼ inch outside diameter and are firmly attached to the lid which covers the cylinder. A rubber hose leads from the top of the glass tube into the collection container (fig. 5).

Procedure

(1) The jar with the field sample is weighed after receiving it at the laboratory and the weight is recorded.

(2) The suspended sediment sample is allowed to stand undisturbed in the field sample jar until the sediment settling on the bottom leaves the water clear. Then the clear water is siphoned off down to about ⅝ inch of the bottom of the jar.

(3) The remaining water with the sediment is washed with distilled water into a steel mixing cup and agitated for five minutes with an ordinary malted milk mixer.

(4) The suspension is washed from the mixer cup into the glass cylinder.

(5) Distilled water is added to the solution until the glass cylinder is filled to within ¼ inch of the top.

(6) The suspension is then agitated so there is a complete dispersion of the sediment throughout the solution. This is done by placing a ground glass plate over the top of the open cylinder and then inverting and righting the vessel a number of times until the sediment is distributed evenly throughout the sample (fig. 5).

(7) The cylinder is then set upright on the rack and the time noted as as well as the temperature of the medium. The siphon and tube and

cover are then placed into position.

(8) Next, the length of time for settling is determined from a prepared chart which was constructed to include the time periods at various temperatures for various size grades. The size grade 0.005 mm. or smaller is determined first. The settling proceeds undisturbed for the computed time interval, (at 20° C. a three hour and 59 minute period is needed for particles 0.005 mm. in diameter).

(9) After the necessary time period has elapsed to allow for the settling of the sediment, the solution is siphoned off down to 32 cm. from the top of the cylinder. The siphoned portion enters into a gallon jar (fig. 6). Throughout the war period only one decantation was used for each size grade; however with the emergency passed and with an increase in personnel, plans are under way to involve three decantations for each size grade. This would entail filling the cylinder with distilled water after step 9, mixing it up again and then allowing the sediment to settle the same amount of time before decantation. This action is repeated a third time; after which all the particles of the certain size grade will have been removed. The reason for the extra decantation is to attempt to extract those fine particles which did not have to fall the entire length of the cylinder or were below the withdrawal point before settling started.

(10) Distilled water is added to the re-

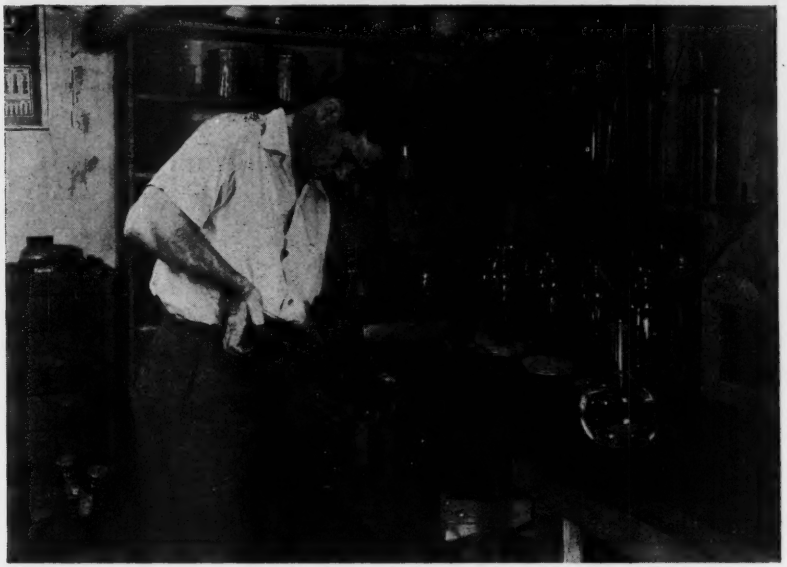


FIG. 5.—Agitating the suspension in the cylinder before allowing it to stand on the rack for the measured time period. Mechanical mixer can be seen to the left of the gallon jars.

maining water-sediment in the cylinder to fill it within ½ inch of the top again. This is mixed and allowed to settle in the same manner as the preceding size grade with the exception of the settling time. Three decantations are also necessary for the 0.0125 mm., 0.030 mm. and 0.074 mm. size.

(11) After the last decantation of each size grade, the container jar is allowed to stand undisturbed for 10 to 14 hours (usually over night) and then the clear water is siphoned off. The remaining material is washed into a beaker.

(12) The sediment and water left in the cylinder after the last decantation contains the particles larger than 0.074 mm. This residue is washed from the cylinder into a beaker.

(13) The next step involves the evaporating of some of the water from the beakers by boiling on an electric range.

(14) While the samples are boiling, the clean, empty jar is weighed and this weight subtracted from the original weight of the jar plus sample as determined in step No. 1.

(15) After the water has boiled down to ½ inch from the bottom of the beaker, the material is transferred to evaporating dishes which are placed into the oven to dry at 110° C.

(16) After the sediment is completely dry, the dish is placed in a desiccator to cool; after cooling, the dish plus the sediment is weighed to 0.0001 gram.

(17) The known weight of the dish is

FIG. 6.—Siphoning off a portion of the suspension in the cylinder into the gallon jar, after the measured time period has elapsed.

subtracted from the weight obtained in the preceding step. This gives the weight of the sediment of that certain size grade which was in the original sample received at the laboratory.

From this laboratory analysis the parts per million of sediment in the water is calculated and plotted on the final form. The discharge of the river at the time the sample was taken is also plotted and with this knowledge the tons per hour of the sediment carried by the river at that particular time is computed. This comprises the basic data—sediment data which are available when various engineering projects are undertaken.

REFERENCES

(1) Report No. 1. Field Practice and Equipment Used in Sampling Suspended Sediment; 1940. Published by the Joint Investigation of A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams.

(2) Report No. 5. Laboratory Investigations of Suspended Sediment Samplers; 1941. Published by the Joint Investigation of A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams.

(3) Love, S. K., 1936. Suspended Matter in Several Small Streams, Trans. Amer. Geophysical Union, 17th Annual Meeting, Part II, pp. 447–452.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 16, NO. 3, PP. 110–120
FIGS. 1–3, DECEMBER, 1946

THE CORRELATION OF SEDIMENTARY ROCKS BY FOSSIL SPORES AND POLLEN

L. R. WILSON
Massachusetts State College, Amherst, Massachusetts

INTRODUCTION

Fossil plant spores and pollen occur in most coals, many shales and some sandstones. In some sedimentary rocks they are found in great numerical and varietal abundance. This knowledge is not new, but the use of spores and pollen as horizon markers for correlation purposes has not been generally appreciated or practiced. Probably the best demonstration of the use of plant microfossils for correlation of strata is the Carboniferous coal work of the British students, particularly that of Raistrick (1937), Millott (1939), and Knox (1942).

Raistrick and Simpson (1933) can be credited with the development of the maceration methods of coal that are at present widely used. They modified and applied methods of peat paleontology to the study of coal seams with remarkable success. Earlier studies were made largely by thin section methods, which do not permit the freedom of spore examination that maceration methods do, since the fossils are imbedded in a coal matrix that obscures many of their structures. In contrast spores and pollen that are freed from the surrounding matrix can be studied in great detail.

In Germany, Russia, and the United States most of the published studies deal with the general description of plant microfossils found in the rock systems. Detailed and convincing stratigraphic work is now in progress in the United States but at present little of that is published.

Plant microfossils may consist of minute plant bodies such as diatoms and desmids, or parts of larger plants, such as woody tissues and cuticles, leaf sections in coal balls, or spores and pollen grains. Diatoms lend themselves very well to certain studies but desmids are quite fragile and appear abundantly only in certain aquatic peats. Woody tissues and cuticles, though abundant in coals and some shales, have not been sufficiently studied to have correlative value. Their limited specific value also does not favor their use. Leaf sections of certain groups of plants may in the future serve in some stratigraphic and paleoecologic studies but at present little has been attempted with them. Spores and pollen on the other hand meet the requirements for correlation work and have proved their worth in, at least, a limited capacity. The chemical nature of spores and pollen is such that most species are resistant to decay. They are varied in their structure and ornamentation which allows the easy identification of many groups of plants and frequently permits specific determination. They are small and are disseminated mainly by air currents. Many species are widely and uniformly spread throughout a region and the sediments in which they may be preserved are numerous.

SPORE AND POLLEN TYPES

Spores and pollen represent a very definite part in the reproductive cycles of plants. At this point in the life cycles there is a departure from the somewhat fixed nature of the organisms. This "motility" arises with the production of spores for dissemination of the plant, or in the production of pollen which may ultimately lead to the fertilization of another plant of a similar species. In the former, the spores are disseminated by air currents and when they come to rest

in favorable situations produce another plant or stage in its life cycle. Many more individuals never reach such localities but may fall into places where fossilization may take place. There are two types of spore producing vascular plants that contribute many spores to the sediments. These are the plants that produce spores of one type such as do the ferns and certain of their allies. Plants of this type are said to be homosporous and their spores range in size from 25 to about 100 microns. The second group of plants produce spores of two sizes. They are the heterosporous plants belonging to various sections of the Pteridophytes. The larger spores, megaspores, are female and the smaller, microspores, are male. The megaspores and microspores differ not only in function but also in size and structure. Megaspores range from about 150 to several hundred microns in diameter or length. Microspores are usually much smaller, being between 30 and 100 microns in diameter or greatest length. Because of their smaller size, microspores are disseminated by air currents more widely and are more uniformly spread over the region than megaspores. For this reason they are likely to be of greater value in correlation studies than megaspores. Pollen also may be described as being of two types, those forms disseminated by air currents, and those carried by insects from one flower to another. There are some species of plants in which both processes of pollination are effective. Pollen of those plants depending totally upon insect pollination cannot be expected to be abundant in sediments. The only way in which such pollen can be abundantly introduced to the fossilizing sediments is by the flowers or parts of the flowers themselves becoming a part of the deposit. In some of the Tertiary coals and Quaternary peats, anthers containing pollen have been found in considerable number, and indicate that at least those species of insect pollinated forms which grow on or near the deposit also may become fossils.

THEORY OF FOSSIL SPORE AND POLLEN CORRELATION

In Raistrick's paper (1934), he states concisely the theory of correlation. "Two assumptions are fundamental in the proposed method of correlation, (i) that the spores, and especially the microspores, were distributed from the parent trees by wind, so that at any one particular time in the coal swamp, the myriads of microspores produced would be mixed and wafted about in the wind so that a fairly uniform scatter was obtained, and the mixing would be such that at any locality a statistical average of all types of spore, would be found; and (ii) that there would be sufficient difference in the make-up of the flora of successive coal seam swamps, to give percentage make-up. These assumptions are based on a long experience of the use of tree pollen as a means of correlating existing peats." The term microspore as used by the British workers does not necessarily mean microspore in the morphological sense but rather it refers to all small spores and therefore may include homosporous species.

Correlation of strata by fossil spores and pollen has at least three factors of biological background that aid in the accomplishment of results. These are: (1) the evolution of floras, (2) the geographic distribution and migration of floras, and (3) the edaphic ecological relations of plants. Through long periods of geologic time, the floras of the world have evolved resulting in marked morphological changes. These changes are reflected in the many forms that occur among spores and pollen. From one geological period to the next, these fossils are frequently very different. Within geological periods climatic and topographic changes have occurred and have caused mass migration or elimination of floras. Sometimes the changes have been cyclic and have permitted the return of many species that were previously forced to migrate. With mass shifting of floras marked changes in spore and pollen fossil species will result in a region, making

differentiation of the strata possible. Local environmental conditions restrict the composition of a flora or cause ecological zonation and serve to limit the fossil content of a stratum. An understanding of these problems aids in stratigraphic studies.

OCCURRENCE OF PLANT MICROFOSSILS

Fossil spores have been known to occur in coal for more than one hundred years. Witham (1833) appears to have been the first to describe their occurrence in the bituminous coals of England. Since then spores or pollen have been found in all ranks of coal, though rare in anthracite. In peats, spores and pollen are abundant and to date most of the plant microfossil work has been done with those sediments. Dawson in 1871 described the presence of disc-like spore bodies (*Sporangites*) from the shales of southern Canada. Since then other shale deposits have yielded an abundance of spores and pollen, especially those of fresh water origin. One notable deposit is that of the Colorado Green River oil shales described by Bradley (1931) and Wodehouse (1933). In these shales the spores and pollen are frequently abundant enough that they overlap one another in the thin sections. Spores and pollen have been found vary rarely in marine limestones but are abundant in marls from fresh water lakes. Consequently they may occur in at least some of the fresh water limestones. Their presence in the calcareous concretions of coal seams is a well known fact and is the source of much of the best morphological material. Sandstones have yielded a few plant microfossils but sandy sediments generally seem not to favor the preservation of spores and pollen. Nevertheless certain conifer pollen grains occur rather frequently in sandy sediments underlying the peat of northern bogs. No spores or pollen are known at present to have been extracted from conglomerates or from recent gravel deposits. From the above it is apparent that these fossils are found in nearly all types of sedimentary rock, but further study is necessary to determine the extent to which they are preserved in various sediments and the best methods of extracting them from their matrixes.

METHODS OF STUDY

Collection

The methods of sampling peats, coals and shales are several. The object of the particular study will somewhat determine what method is best. The common practice of taking workable samples of peat is to collect specimens at vertical intervals through the deposit. The length of the intervals usually varies with the thickness of the deposit and its sedimentary structure. The same practice may be used in coal or shale deposits but the greater amount of compression that has occurred in coal beds does not seem to permit as close horizon comparison as in peat. A second method, and one that is generally applied to coal, is the practice of cutting a channel sample from the face or outcrop. This may consist of chipping a uniform sample completely through a seam, or dividing it according to the number of shale or pyrite partings. Such a practice has proved very satisfactory for correlation purposes, but it is limited in its use for fossil successional studies. In order to apply paleocological methods in correlation studies, it is necessary to take somewhat definite segments from the channel. Figure 1 illustrates the methods of collecting samples.

Maceration

The preparation of sedimentary rocks for plant microfossil studies differs greatly with the type of material to be investigated. The clastic sediments yield spore and pollen fossils readily by simple dispersion which consists of boiling the material in water with the addition of various amounts of potassium hydroxide or ammonium hydroxide. When complete dispersion has been achieved, the mixture may be passed through a fine mesh screen

to remove the larger particles. The material is then ready for examination. More elaborate and refined methods of preparing peat, silts, and clays have been worked out by European and American students. For these, reference may be made to the excellent treatise by G. Erdtman (1943).

For the preparation of consolidated rocks other methods are usually necessary. The different ranks of coal vary in structure and it is frequently necessary

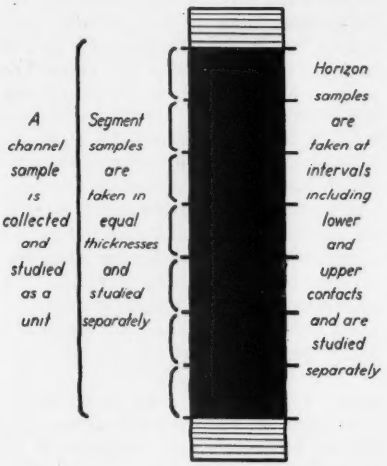

A channel sample is collected and studied as a unit
Segment samples are taken in equal thicknesses and studied separately
Horizon samples are taken at intervals including lower and upper contacts and are studied separately

FIG. 1.—Types of samples that may be taken from a coal seam for microfossil studies. When shale or pyrite partings occur the coals above and below are treated as distinct parts.

to experiment with several methods of maceration. Some of the low rank coals can be prepared in the same manner as peat but usually it is necessary to use strong solutions of potassium hydroxide or ammonium hydroxide to prepare the coarsely pulverized coal. Whereas peat frequently disperses immediately it is sometimes necessary to allow the coal to remain in the digesting solution a number of hours. When the digesting process is completed it is necessary to dilute the solution with water and by a series of decantations or by centrifuging to obtain the residue which consists largely of spores, pollen, and vegetative plant parts.

The work with higher ranks of coal, and some lower, involves the use of stronger digesting solutions than is necessary with most brown coals. The most frequently used method is that with Schultze's solution for a period of twelve to eighteen hours. Several grams of finely broken coal are placed in a beaker and covered with Schultze's solution. Since the chemical reaction may be violent, it is desirable to carry on the process under a laboratory hood. In the course of the digesting process, the mixture should be stirred several times with a glass rod. If at the end of about twelve hours all apparent reaction has stopped, the mixture is washed with water and decanted. Usually it is necessary to decant the material several times. After the last washing the coal sediment is covered with ammonium hydroxide and allowed to remain another twelve to twenty-four hours. It, too, should be stirred several times in the course of the process. At the end of the ammonium hydroxide application, water is again added and decanted. After the second decantation, the liquid may be centrifuged and washed until there is no longer a detectable odor of ammonium hydroxide. Stain may be added to the sediment at this point and when the proper intensity is obtained, the material is washed until the water no longer is colored. Temporary water mounts may be made and used for study without further preparation.

Frequently the above schedule will not apply to certain higher rank coals for some will macerate more or less easily than others. In some coals the fossils will be badly corroded, while in others the fossils will not be separated from the matrix, consequently it will be necessary to modify the time of Schultze's solution treatment. Therefore it is desirable to keep rather complete notes on the procedure used on each sample. A modification of Schultze's solution method has

been developed by Raistrick (1937). He has found that good results are obtained by mixing an equal amount, by weight, of coal fragments and powdered potassium chlorate. To this mixture is added about fifteen times as much concentrated nitric acid. The writer has found the chemical reactions of this method to be much more violent with some of the American coals than by use of Schultze's solution and the results are not sufficiently better to warrant its use.

The preparation of shales and fine sandstones for spore and pollen study involves the use of hydrofluoric acid for the solution of the associated silica particles. The technique with various shales and sandstones appears to be very specific and a certain amount of experimentation is necessary with each particular rock. Before the hydrofluoric acid method can be undertaken, special equipment consisting of copper or lead beakers and centrifuge tubes must be secured. In preparing shales for the hydrofluoric method they should be broken into splinters of about $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter. The sample is then placed in a copper or lead beaker and covered with hydrofluoric acid. The length of time necessary for the maceration of the sample varies from twelve to about sixteen hours. The material is then centrifuged in copper or lead tubes to remove the excess acid. The residue should be washed and centrifuged several times before stain is added. The procedure from this point can be the same as described for the coal technique.

Work with hydrofluoric acid must be done with utmost care to prevent serious burns and one should be thoroughly acquainted with the first aid treatment.

Microscopic mounts

When maceration is completed, the fossils may be stained with safranine or other stains or be studied unstained as water mounts. If the material is to be prepared for permanent study, the excess water may be extracted first by centrifuging, then by dehydrating with progressively greater strengths of alcohol, depending upon the nature of the mounting medium to be used. If glycerine jelly is used, the moist sediment recovered after centrifuging can be spread on a microscope slide and allowed to lose additional water by evaporation. When the sediment reaches the state of being only slightly moist a drop of warm glycerine jelly may be placed on it and stirred until the material is uniformly distributed. A warm No. 0 cover glass is then placed over the drop and the slide is inverted and placed horizontally in a rack to harden. Glycerine jelly mounts have proved satisfactory for material that is kept over a period of a few years. For permanent slides it is necessary to ring the cover glass when the glycerine jelly has set. The disadvantages of glycerine jelly are that they do not remain sufficiently set in warm seasons or climates, and they also have a tendency to develop air cavities if the fossil material is not sufficiently washed after the digesting process or dried before applying the glycerine jelly. To insure removal of water from the glycerine jelly mixture a small quantity may be placed in a calcium chloride desiccating jar for twenty-four hours or more. Other media have been used which are equally satisfactory for microscopic examination of the fossils but they require somewhat more complicated preparation. Some workers have made permanent mounts with Canada balsam but the high index of refraction of this mounting medium is a disadvantage in most studies. Euparal and diaphane are among the best media that are widely used. These require the dehydration process of alcohol mentioned above. The fossils may be mounted in euparal directly from the centrifuged sediments of 95 per cent alcohol. As with glycerine jelly, care must be taken to allow the material placed on a microscope slide to dry somewhat before adding the drop of euparal. Another method of making microscopic slides is the dispersal of a small amount of slightly alcohol-moist sediment in several cc. of euparal.

When the material is completely stirred and dispersed, a drop of the mixture is placed on a warm microscope slide and covered with a warm cover glass. As before, the slide should be inverted and placed horizontally to set. Diaphane mounts may be prepared in essentially the same manner except that it is necessary to follow the alcohol treatment by a diaphane preparatory solution.

The proper concentration of sediment on the slide can be determined with practice. Usually it is desirable to have rather a wide dispersal of particles on the slide. This permits better examination of individual fossils, and photographs of specimens do not have associated debris. For statistical counts, however, it may be desirable to have a greater concentration of the sediment. This reduces the amount of microscopic scanning, though frequently it adds to the problems of specific identification.

Microscope equipment

Since the examination and study of plant microfossils is almost totally microscopic, it is necessary to have equipment that will permit systematic scanning with a minimum of eye strain. Various methods of microscopic projection have been attempted without satisfactory results. In the study of megaspores a binocular with low power oculars and objectives is satisfactory but the study of smaller spores and pollen grains requires the use of a good compound binocular microscope. It is desirable to have oculars of 5X, 10X, and 15X and objectives of 10MM, 3MM, and an oil immersion lens. With this set of oculars and objectives, one is able to use various combinations and secure any desirable magnification. These same combinations of oculars and objectives can also be used in making photographic records. The microscope should also be equipped with a measuring device. One of the simplest is an ocular measuring disc. It can be kept permanently in one of the oculars or may be mounted in a duplicate ocular and removed when not in use. The stage of the microscope should be equipped with a calibrated mechanical stage. Most studies are carried on by the use of substage illumination and transmitted light. Certain fossils, however, are opaque and it is necessary to have the microscope equipped with a vertical illuminator for direct lighting. This is especially necessary when working with the megaspores.

When new material is being examined, it is desirable to make camera lucida drawings or photographs of the fossils as they are found. There are various methods of making photographic records as well as numerous types of photographic equipment. A very satisfactory procedure is to have a separate monocular compound microscope permanently set up with a camera for photomicrographic work. When a desirable fossil is encountered under the binocular, its position can be calibrated with the mechanical stage or it can be ringed on the cover glass with glass ink or wax pencil. The slide then may be transferred and the fossil photographed.

Designating plant microfossils

Several methods have been used by micropaleontologists to designate the specific identity of the spores and pollen fossils. These differ according to the uses to which the studies have been directed. Also they vary with the geological age of the material and the state of morphological knowledge of the plants to which they are related. Many of the Cenozoic fossils can be definitely identified with existing groups of plants. Others can be tentatively placed in artificial groups and serve as satisfactory stratigraphic indices. More and more frequent are the forms that cannot be assigned to known families or orders of plants as one progresses backward through geological time. There are two reasons for such difficulty: namely, the incomplete knowledge of modern spore and pollen morphology, and the occurrence of numerous extinct groups of plants. As the study of modern

spore and pollen morphology progresses the former difficulty gradually will be resolved. The second never will be entirely eliminated for the possibility of discovering fructifications of plants is very limited. However, the number of spores known from fructification material is surprising. Much of this information has come by way of coal ball studies. Concretions of that type are not at present known from the Mesozoic or Cenozoic rocks, and therefore a definite limitation exists in the younger rocks. Impression material of flowers seldom yields any associated pollen. The great rarity of fossil flowers is also a limitation in the study of natural pollen affinities. However desirable it is to know the affinities of spores and pollen to their producing plants, it is not necessary for stratigraphic work to wait until such knowledge can be attained. Several systems of designating spores and pollen have arisen that have proved satisfactory to stratigraphic work.

Raistrick and Simpson (1933) and other British workers have designated the identity of certain Carboniferous spores with a letter to represent general types and a subnumber to represent specific forms. Raistrick established six spore groups and designated those as letters A to F inclusive. In each group numerous specific forms are designated as A_1, A_2, A_3, etc.

The German workers under the leadership of Ibrahim (1933) have attempted to establish an artificial binomial system of classification for spores based upon the structural condition of the germinating aperture. Three major groups were established: (1) those spores without a germinating aperture (Aletes), (2) spores with one germinating slit (Monoletes), (3) spores with a trilete aperture (Triletes). Under these three groups, genera were established on the basis of spore coat ornamentation, such as degree of smoothness, reticulation, punctation, etc. In this classification no attempt was made to separate megaspores and microspores. To designate that the fossils are spores, the generic name carried the hyphenated suffix "*-sporites.*" In the fossil studies of Potonie and other Germans they found it desirable to recognize certain natural pollen affinities and use modified established generic names with the hyphenated suffix, for example *Tilia-pollenites*, and *Alni-pollenites.*

In this country Schopf, Wilson, and Bentall (1944) reviewed the existing systems of classifying the Paleozoic spores and attempted to place the descriptions of these fossils on the basis of the International Rules of Nomenclature and to assemble them into more or less natural groups. This taxonomic revision is in the form of an annotated synopsis of several hundred Paleozoic fossil spores and the definition of generic groups. The plan to use the International Rules of Botanical Nomenclature appears to be the most sound method of treatment. Fossil pollen forms will need further study and since most pollen producing plants are either Mesozoic or Cenozoic in age, the ultimate classification of forms will probably parallel rather closely that of accepted phylogenetic systems. Since many of the Mesozoic spores and pollen probably belong to extinct genera of plants whose natural affinity cannot be ascertained, form genera will have to be established. Such a situation also exists with respect to certain of the Cenozoic pollen and it will be necessary to apply the same treatment. Many, however, can be assigned to existing families or genera and may carry the valid generic name or a modified family or generic name. Such a system was established by Wodehouse (1933). He proposed that fossils whose identification was relatively certain with respect to the family but remain unknown as to genus would carry the root name of the family plus the suffix "*-pites.*" If the fossil can be identified with some assurance to an existing genus then the root of the genus is used with the suffix "*-pites.*" Where the generic relationship

is positive, the valid generic name is used. If the fossil resembles an established species of modern plant but there is some question as to its certainty, the root of the specific name of that species is supplemented with the suffix "*-pites.*" Such a system permits an immediate understanding of the taxonomic position of the fossil and its relative status in present knowledge. There are, however, scores of pollen fossils that cannot be so classified because of the incomplete knowledge of modern pollen morphology. These must be treated in a somewhat artificial classification based possibly on morphological characters such as number and structure of furrows and pores. Such a suggestion was made by Erdtman (1943) but until this suggested generic classification is more fully described, it is not taxonomically valid.

The procedure frequently used in microfossil studies of spores and pollen which lead to the description of new forms is to isolate and study structurally specimens of the common and well-preserved types. Specimens are permanently located and descriptions, photographs, and drawings are prepared of the fossils. Holotype or cotype specimens are chosen and described following the procedure of the International Rules of Botanical Nomenclature (1935). In addition it is desirable to include a statement concerning the abundance and stratigraphic distribution of the fossils.

Correlation work

Spores and pollen that occur in the samples may be designated as either dominant or accessory species depending upon their abundance. Usually the dominant species occur in the frequency of 5 or more per cent of the total count in the sample. The accessory species are less frequent and sometimes are not represented by more than a single specimen in a count of one thousand. With the present state of knowledge concerning the distribution of the fossils the dominant species are of most value in correlation studies, but as the vertical and geographical ranges are better understood the accessory species will become more significant. This assumption is based upon the possibility that some of the spores or pollen may have come from plants of restricted vertical range in the rocks, of specific paleoecological conditions, or of important index species that produced comparatively few spores or pollen.

For stratigraphic work the fossils occurring in the samples may be divided into the following three groups: (1) knowns, (2) unknowns, and (3) those broken beyond recognition. The "knowns" are those fossils that are recognized as species already described or tentatively given descriptions. They are recorded and used in correlation work. The "unknowns" are those fossils that are undescribed and are usually not abundant. Some of these later may be found to be important dominant or accessory species, but in the preliminary work usually are not used. They are lumped under the heading of "unknowns." In the counts it is desirable to have a record of the number of unknown forms and to prepare descriptive illustrations of the more diagnostic types. Those fossils that are broken to the point where they cannot be identified with described species are ignored in the counts. It is assumed that all species except certain resistant forms will break down in approximately the same ratio or in specific ratios that will not materially affect the final count.

The number of spores and pollen that should be counted for satisfactory correlation work appears to be based on the use to which the study is directed, and the number of species present in samples. In peat investigations, pollen of tree species are usually the only ones used and the conclusions are usually based upon a count of 200 fossils. In peat seldom more than a dozen plant species are present and frequently the total number of tree pollen species are not

more than six in any one level. In coal and shale studies the paleontologist uses all types of spores and pollen and seldom restricts his studies to tree pollen. For this reason the number of species are often several times the number encountered in peat. Consequently, it is desirable to examine and count a greater counted, and 500 where a dozen or more species were involved.

Graphic treatment of the counts is probably the best method of demonstrating plant microfossil correlations. Line graphs were early used in peat pollen studies to show paleoecological succession, but these have been largely

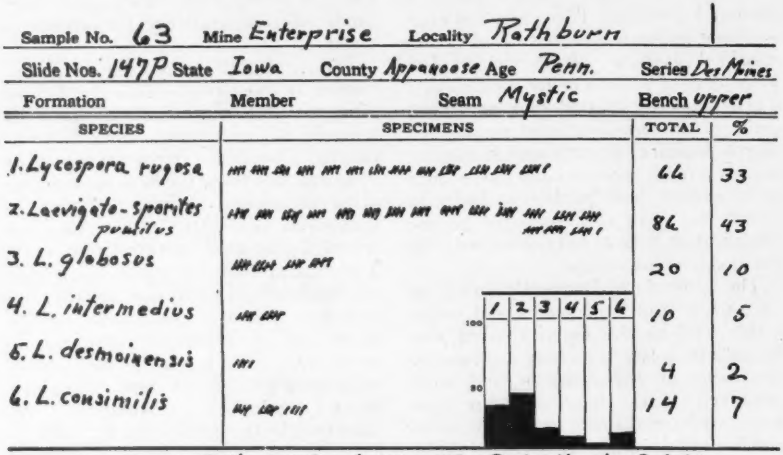


FIG. 2.—Card used in recording a coal seam study. It contains data on collection, preparation, analysis, and geological interpretation. In the lower right an histogram of the bench is drawn based upon the percents in the right hand column.

number of individuals. What this count should be is not established and differs widely among workers. When Raistrick began his Carboniferous coal work in England, he counted several thousand individuals. Knox (1942), working with the Scottish coals, counted 200 or more fossils for correlation purposes and attained satisfactory results. Potonie (1934) studying the German Tertiary coals, counted between 100 and 211 spores. In this country the exploratory work has usually been done with counts of 1000; however, satisfactory correlation results have been attained with counts of 200 where 6 or 8 dominant spores were replaced by bar graphs of several types. Raistrick and Simpson (1933) instituted a bar graph similar to the one illustrated in figure 2, which has proved an effective means of graphic representation. Since the scale of the graph is comparatively small, only the dominant microfossils are used. When accessory spores are graphed the scale must be materially increased, or if it is desirable to place both dominant and accessory fossils on the same graph then a semi-logarithmic scale can be used.

Two types of graphs can be constructed for correlation purposes. These are channel sample graphs and horizon segment

graphs. The former is the better type for direct correlation purposes, if the strata involved are not more than several feet thick. In thick coal seams, channel sample correlation becomes difficult. Where possible, a coal seam should be divided into segments separated by shale or pyrite partings. These partings are often of extensive areal extent and make good natural boundaries. In shale deposits lithological types should be used to limit the extent of the sample. In order to determine paleoecological succession within a rock member, contiguous thin vertical samples must be studied. The graphed results will show the percentage of the fossils at successive levels (fig. 3). Close correlation of comparable measured horizons have not yet shown exact percentages of identical species, but successional trends are usually indicated, if the section is viewed as a whole, and as such have paleoecological and stratigraphic value.

How similar the percentages of each fossil species must be in strata to indicate correlation is a question of considerable pertinence. Experiments with seams of coal have shown that the dominant fossils will frequently vary between 5 and 10 per cent in a 200 fossil count, if the samples are collected several miles apart, or the maceration process has not been uniform. In the first instance, areal distribution of the ancient vegetation apparently is a factor, or the coal seam was thicker or more completely represented at one locality than at another. In the second instance, where uniformity of maceration is not attained, fossils with various thicknesses of spore or pollen coat, or great differences in size, will appear in variable percentages. An effective method of combating such problems

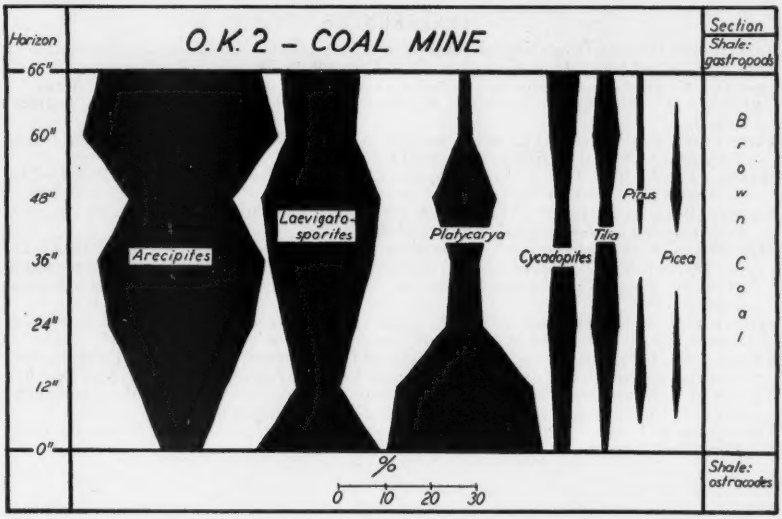


FIG. 3.—A paleoecological histogram showing the microfossil succession of several important genera in a Tertiary coal seam. This diagram is based upon percents in a series of horizon samples.

is to divide the sample in the course of its preparation and allow additional time for each portion of the sample. Uniformity can be checked with test slides using the corrosion of certain species of fossils as an index for uniformity of maceration.

In conclusion, it might be stated that results have been attained with fossil spores and pollen which show conclusively that all coals and shales thus far studied can be assigned within the limits of geological periods, and that various strata can be separated from each other by their spore and pollen facies, or specific abundance of various species. It would seem that plant microfossils have great future scientific and economic value as the science develops and broadens.

REFERENCES

BRADLEY, W. H. *1931.* Origin and microfossils of the oil shales of the Green River formation of Colorado and Utah. *U. S. Geol. Surv. Prof. Pap.* 168: 1–58.

ERDTMAN, G. *1943.* An introduction to pollen analysis. Chron. Bot. Co., Waltham, Mass.

IBRAHIM, A. C. *1933.* Sporenformen des Aegirhorizonts des Ruhr-Reviers. Diss., K. Triltsch, Würzburg.

KNOX, ELIZABETH, M. *1942.* The microspores in some coals of the productive coal measures in Fife. *Trans. Inst. Min. Engin.* 101: 98–112.

MILLOTT, J. O'N. *1939.* The microspores in the coal seams of North Staffordshire. Part I—The Millstone grit—ten foot coals. *Colliery Guardian* 158 (4074): 151–153; (4075): 200–204.

POTONIE, ROBERT. *1934.* Zur Mikrobotanik der Kohlen und ihrer Verwandten. Pt. II. *Arb. Inst. Palaobot., Petrogr.*, Brennsteine 4: 25–125.

RAISTRICK, A. *1934.* The correlation of coal seams. *Armstrong College Min. Soc. Jour.* 10: 14–22.

———. *1937.* The microspores of coal and their use in correlation etc. Tire de Compte rendu du deuxieme Congres pour l'avancement des etudes de stratigraphic Carbonifere-Heerlen 1935. Pp. 909–917.

RAISTRICK, A. and J. SIMPSON. *1933.* The microspores in some Northumberland coals, and their use in the correlation of coal seams. *Trans. Inst. Min. Engin.* 85: 225–235.

SCHOPF, J. M., L. R. WILSON and RAY BENTALL. *1944.* An annotated synopsis of Paleozoic fossil spores and the definition of generic groups. *Report of Investigations of Ill. Surv.* No. 91.

WITHAM OF LARTINGTON. *1833.* Internal structure of fossil vegetables found in the Carboniferous and Oolitic deposits of Great Britain, described and illustrated.

WODEHOUSE, R. P. *1933.* Tertiary pollen—II. The oil shales of the Green River formation. *Bull. Torrey Bot. Club* 60: 479–524.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 16, NO. 3, PP. 121–123
FIG. 1, DECEMBER, 1946

SEDIMENTS FROM ALASKITE, CAPITAN MOUNTAIN, NEW MEXICO

RAYMOND SIDWELL
Texas Technological College, Lubbock, Texas

ABSTRACT

Intrusive rock, alaskite, in Capitan Mountain is reduced to fragments under semi-arid conditions and at altitudes above 7,000 feet. Materials at the time of disintegration are arkosic: some accumulate on the alaskite but most are deposited at lower levels in the piedmont. Mineral content of the sediments in order to abundance are quartz, feldspars, magnetite, staurolite, hornblende, anatase and andalusite. Most of the minerals have undergone some degree of alteration.

INTRODUCTION

Capitan uplift (fig. 1), an isolated unit of the Sacramento Mountains in south-central Lincoln County, New Mexico, has an east-west extension of 25 miles and a maximum width of five miles. Rocks in the uplift are primarily plutonic. The intrusive breaks through upper Cretaceous sediments and attains an altitude of 10,000 feet in Capitan Peak.

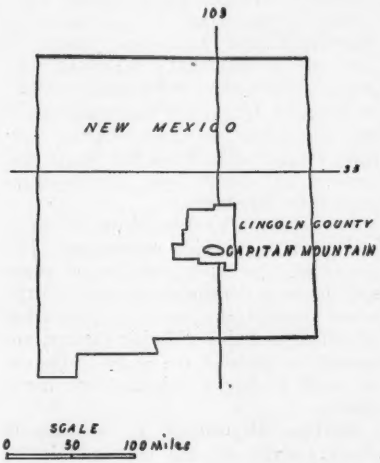


FIG. 1.—Map showing general location of Capitan Mountain.

Plutonic rocks in Capitan uplift, classified by Patton as alaskite (oral communication), are holo-crystalline, light colored, granular and uniform. Constituents of the alaskite are feldspars, orthoclase and sodaclase, quartz, a minor amount of brown and green hornblende, and a few accessory minerals. Hornblende is about 3 per cent; accessory minerals are about 7 per cent; quartz is about 40 per cent; others are feldspars, chiefly microline and a small amount of albite (Ab_{10}). Two varieties of quartz, transparent and milky, are represented. Accessory minerals, magnetite, staurolite, anatase and andalusite, are numerous in the peripheral parts of the alaskite. In addition to disseminated grains, magnetite occurs as huge pockets of high grade ore which has been worked commercially.

Deposits of recent detritals radiate out from the base of the alaskite and cover the sedimentary rocks at the zone of contact. Permian, Triassic and Cretaceous sedimentary rocks are exposed. The Permian consists of grayish-white, dolomitic limestones interlensed with thin layers of red shale. Some of the beds carry braciopods, gastropods and other fossils. The limestones are probably the contact rock at the east end of the uplift. Triassic rocks, probably Dockum in age,

crop out at the south border of the detritals. They consist chiefly of gray, conglomeritic, non-marine sandstones and red shales. The basal part of the Cretaceous, Greenhorn, is a dark resistant limestone with a maximum thickness of 20 feet. Above the limestones are dark gray, calcareous shales, probably Carlisle, which contain large septated concretions and attain a thickness of 130 feet. Cretaceous sediments border the uplift to the west and north.

Field work involved collecting materials and observing the general characteristics of the sediments and the intrusive. Thin sections were utilized to classify the plutonic rocks. Sediments were analysed for mineral content, shape and general characteristics of the particles, and the degree of alteration.

CHARACTERISTICS OF THE SEDIMENTS

Disintegration of the alaskite under the semi-arid conditions and the protection of a vegetable cover occurs at altitudes above 7,000 feet, except on the precipitous south-facing slopes. Materials at the time of disintegration are arkosic: particles are angular, contain a high per cent of feldspar, and range in texture from fine sand to boulders. A small amount of the detritals accumulate on the intrusive but most are transported by gravity and rainwash to lower levels and deposited in the piedmont where they are undisturbed except for some reworking in the small arroyos.

Sediments in the piedmont are poorly stratified and range in texture from boulders and cobbles in the basal part upward into sands and clays. The boulders are sub-angular, composed of light colored, granular materials, and commonly occur in a matrix of sand and clay. Most of the sediments are of sand size. The grains are sub-angular to sub-round and most are in the size grade of $\frac{1}{4}$ to $\frac{1}{2}$ mm. Clay and silt particles are characterized by a dark-gray color, an absence of carbonates, and have kaolinite properties.

Detrital minerals in order of abundance are quartz, feldspars, magnetite, staurolite, hornblende, anatase and andalusite.

Quartz—Two varieties, transparent and milky, are represented. The grains are sub-angular to sub-rounded; some contain circular solution pits; and a few are partly coated with iron oxide. Quartz is characterized by the concentric ring interference colors, numerous inclusions of dark colored minerals and gas bubbles, and weakly developed strain shadows.

Feldspars—About 40 per cent of the minerals in the light fraction (specific gravity less than 2.6) are feldspars. Two varieties, microcline and albite, are present. The grains consist chiefly of milky-white to gray platy fragments: some are unaltered but most have undergone some degree of decay.

Magnetite—About 60 per cent of the heavy minerals are magnetite. Particles range in size from fine sand to rounded boulders six inches in diameter. Grains of sand size consist of irregular fragments and a few well developed octohedral crystals. Magnetite is concentrated in the detritals at the east end of the uplift.

Staurolite—Maximum occurrence of staurolite is in the deposit south of the uplift. It is second to magnetite in abundance and composes about 26 per cent of the heavy minerals. The grains are brownish-yellow, consist chiefly of irregular fragments with haphazard boundaries and contain numerous fractures which radiate from the center. Inclusions of quartz and carbonaceous matter are numerous.

Hornblende—Various shades of brown and green hornblende were noted. The grains are elongated with jagged edges and the color density decreases from the center toward the margins. Alteration products, probably chloritic matter, are present on most of the grains. About 6 per cent of heavy minerals are hornblende.

Anatase—Occurrence of anatase is about equally divided between simple and compound octohedrons and irregular fragments. The grains are black, almost opaque and unaltered. Pyramidal zoning

is present on a few of the crystals. About 4 per cent of the heavy minerals are anatase.

Andalusite—This mineral is represented by well developed prisms with pyramidal terminations and much fractured grains. Carbonaceous inclusions as narrow bands parallel the long axis of the crystals. Solution pits are numerous. About 4 per cent of the heavy minerals are andalusite.

ALTERATION

The feldspars and magnetite in the ankosic deposits on the intrusive evidently were partly altered during disintegration of the alaskite. Dark-colored, nearly opaque materials with irregular boundaries are present along fractures and cleavage planes of the feldspars. Magnetite grains, as shown in the rust colored surface streaks, are in an early stage of decay.

Some materials in the piedmont deposits have decomposed into silts and clays. Alteration of the feldspars is especially apparent. The vitrous luster, typical of the arkoses, is absent: grains are pitted and under reflected light are almost opaque. In addition, a few fragments of feldspar are easily powdered into clay-like particles with kaolinite characteristics. Various degrees of decay are apparent in about 50 per cent of the magnetite. Many grains contain reddish-brown surface streaks; whereas, others are almost completely altered to hematite. Edges and frayed ends of most of the hornblende are altered to chloritic matter. A few grains of andalusite have a turbid appearance; others, especially the crystals, contain deep solution pits.

CONCLUSIONS

Rocks in Capitan uplift are chiefly alaskite which readily breaks down into arkosic materials. A small amount of the arkoses accumulate on the intrusive but most of them are deposited in the piedmont. Most of the materials have undergone some degree of alteration: some have been reduced to clays and silts. Mineral content of the detritals in order of abundance are quartz, feldspars, magnetite, staurolite, hornblende, anatase and andalusite.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 16, No. 3, PP. 124–128
DECEMBER, 1946

A COLOR-NUMERICAL SYSTEM AS APPLIED TO WELL LOGS*

D. C. MADDOX
Associate Geologist, Geological Survey of Canada

ABSTRACT

The advantages of a standard condensed graphic method of expressing the results of the examination of well samples are here considered. A tentative scheme for this purpose is here proposed. This scheme is probably unnecessarily detailed for use in oil fields which have been long developed and in which formation contacts are clearly defined. Its special value seems to lie in the preparation of well logs from wildcat areas, or from areas in which sub-divisions of well known formations are contemplated. The scheme here given is tentative and the article is written less with the idea of establishing a rigid system than of stimulating an exchange of ideas on a very important subject that has not received much publicity.

The writer has long been interested in the development of a condensed, logical system of expressing the results of sample examination. Having had the opportunity of examining well logs that have been prepared by many different workers, he has been deeply impressed by the apparent absence of uniformity in the methods of examination used; the remarkable variety of ways of expressing the results of the examination; and the presence of so many gaps and deficiencies that so many of those logs present to the eye of the reader.

Literary experts claim that the description of an object should be so complete that by means of it an artist could paint a picture. It is hardly likely that an artist would set-up canvas and easel before a well log, but if he did, how would he express such items as "Chiefly dark shale"; "Generally as above"; "Greyish-buff dolomite"; "Spearfish"; "Lime" etc.?

A few of the necessary conditions that should be fulfilled by an efficient numerical method for expressing graphically the log of a well are as follows:

The method should be as simple and rapid as is consistent with exactness and completeness.

It should be readily convertible both into a written log, a colored log, or a black and white log.

It should make provision for the recording of all constituents in the sample, special emphasis being laid upon the recording of the occurrence of rocks or minerals that are likely to indicate formation contacts or key horizons.

It should record the results of examination quantitatively as well as qualitatively.

It should as far as possible conform with existing conventions.

With these considerations in mind the following color-numerical scheme has been devised.

The standard colors in the chart prepared by the Committee of Sedimentation seem to be too numerous for rapid work but a chart based on a few standard shades of brown and of grey, and their combinations, with numbers attached, and fitting into the color scheme here given, would be very useful.

If standard colors are difficult to obtain it might be well to consider the use of standard colors of modeling clay, such as white, grey, black, brown, red and green. Weighed charges of the clays could be mixed to form a fairly small group of intermediate colors that for use could be mounted between glass slides.

The writer has long used a system of color description in which the modifying

* Publication authorized by the Chief Geologist, Geological Survey of Canada.

color is placed on the left, the principal color on the right. Three columns, each half an inch wide, were used. The left column was used for the expression of color, the centre column was reserved for formation contacts and occurrences of oil, gas, and water; the right column expressing the lithology. Thus, a light grey would read—white, one tenth, grey four-tenths; dark brownish-grey—black, one-tenth; brown, one-tenth; grey three-tenths. This system is intended to replace the use of such terms as "tan," "buff," "mauve" etc. A system of masks for covering one of the two color columns, or for isolating sections of the log, was used to avoid confusion.

The use of the colors. Most of the numbers from 1 to 20 have their corresponding colors, but in the small areas covered in the parts of the well log it is suggested that two colors be used in combination when any uncertainty is likely to result from the use of a single color. Thus, although the number 13 corresponds with greyish-green, this color is more easily recognized if it is plotted as two colors, grey-green. Again, the intermediate colors are too much like the principal colors for use in small areas and two colors should be used for this purpose also, thus greenish-blue, green-blue.

It will probably be necessary to transfer from numbers to colors only those parts of the log that are significant for stratigraphic purposes, as those parts of the lithological log where notable changes occur, or where evidences of changes of conditions of sedimentation are found.

Lithology. The five principal colors are well adapted to the expression of lithology, the color number being preceded by "one" to show that the rock is calcareous, by "six" to show that it is dolomitic.

A method of distinguishing calcitic limestone from dolomitic limestone by the use of dilute hydrochloric acid, 1:4 cold, and then hot, has long been in use by the writer. The speed of effervescence is expressed by a series of numbers from 0 to 7. The method is admittedly very approximate but it possesses the great advantages of speed and of being readily "plotable." For accurate comparative work, of course, the method would involve the use of a weighed charge of closely screened material, of a measured volume of dilute acid, and of closely controlled conditions of time and temperature. By its use the distinction between pure calcitic limestone (6.7) and pure dolomitic limestone (0.7) is very marked, but for intermediate magnesian values, or for impure carbonate rocks, it is less reliable. A number of devices, such as measuring the volume of the carbon dioxide evolved with a time or pressure control, could be devised, but all such methods require time. The distinction between calcitic limestone and dolomitic limestone is often of great importance. By the use of figures, the rate of effervescence may be plotted, but if this distinction is not essential it is suggested that the speed of effervescence figures be added enclosed in parentheses. Thus a light brown dolomitic sandstone would be expressed as 26-62 (0.3); a slightly calcareous sandstone as 10-2 (2–3).

Ironstone, of course, will give effervescence figures similar to those for dolomitic limestone, but ironstone can usually be distinguished by its color, or by the use of heavy liquids.

Quantitative considerations. The technical terms here used are self-explanatory. In the rapid approximate estimation, which is the best the sample examiner can usually do, the limits of the classes seem to be sufficiently accurate. Such a scheme challenges the sample examiner to include all materials of the sample in his log, and to adjust his quantities so that the total shall not exceed 100%. It relieves him, however, of the mental strain of attempting to get his percentages down to an exact figure. The proportions may be expressed as numbers, capital letters, or words.

Fossils. With the exception of microscopic fossils such as foraminifera or ostracods the fossils in well samples are usually so fragmentary that no definite

A Color-Numerical System for Sediments

Serial No.	Color		Grain Size	Lithology		Quantitative				
	Modifying	Principal		Modifying	Principal			Percentage		
								Low	Mean	High
00	Very dark		Lithographic							
0	Dark	Black	Dense							
1	Reddish	Red	Very Fine	Conglomeratic	Conglomerate	Trace	Tr.			
2	Yellowish	Yellow	Fine	Sandy	Sandstone	Very little	V.L.	1	2	3½
3	Greenish	Green	Medium			A little	L.	3½	5	6½
4	Blueish	Blue	Coarse	Silty	Silt	Considerable	C.	6½	10	12½
5	Purplish	Purple	Very coarse	Shaly	Shale	Much	M.	12½	20	25
6	Brownish	Brown		Dolomitic	Dolomite	Very much	V.M.	25	37½	50
7						Dominant	D.	Over 50%		
8						Superdominant	S.D.	Over 90%		
10	Greyish	Grey		Calcareous	Limestone					
11	Greyish red			Calcareous conglomerate						
12	Greyish yellow			Calcareous sandstone						
13	Greyish green			Calcareous sandy shale						
14	Greyish blue			Calcareous silt						
15	Greyish purple			Calcareous shale						
16	Greyish brown			Calcareous dolomite						
20	Light	White								
21	Light red									
22	Light yellow, etc.									
30	Very light									
31	Very light red									
32	Very light yellow, etc.									
51	Shaly conglomerate									
52	Shaly sandstone									
61	Dolomitic conglomerate									
62	Dolomitic sandstone, etc.									

Example. Very light brown, very fine grained, glauconitic calcareous sandstone, superdominant; very hard; poorly laminated, non-porous; effervescense figures 2:4 =36.1 – gl. 12 S.D. – 5, 2, 0 – (2:4).

identification is possible. Clastopaleontology, the science of fossil fragments, seems never to have been adequately developed. No attempt has been made to apply the number system to paleontology this being left to the judgment of the local paleontologist. It is desirable, however, that at least an attempt be made to replace the very indefinite term "shell fragments" by some number system that will attempt to describe some of the more important features such as color, thickness, curvature, structure, surface features, and mineral and chemical composition of those fragments. Even the presence at certain horizons of many shell fragments of a certain type may be of value for correlation purposes. In the western Cretaceous sediments a few fairly well defined types of shell fragments can be distinguished. Brilliantly iridescent, characteristic of baculites or some marine pelecypods; columnar calcite type, usually associated with Inoceramus shells; pearly, suggestive of Unio shells; dull and porous, recalling oyster shell structure, etc.

Stratigraphic numbers. These are intended purely for convenience and economy of space and have no relationship to the relative lengths of the periods to which they are assigned. They have the advantage of readily making provision for future sub-division by addition of numbers. Thus, in a wildcat well, a "3" would show the formation to be Paleozoic in age. When the formation was later identified as Devonian in age a "4" would be added to the "3." Further detailed work might narrow the age of the sample down to the upper part of the Middle Devonian—"3423." The numbers also clearly indicate a gap in the stratigraphic sequence.

Conditions of Deposition. This column may not be continuous but it seems worth while to have some means of expressing graphically whatever evidence is available as to the conditions under which the sediments were deposited, such as marine

A Color-Numerical System for Sediments

Hardness	Lamination	Porosity	Stratigraphy		Conditions of Deposition	Mineral	Effervescence with Acid	
							No.	Speed
	None	None	Early			Coal	0	
Very soft	Very poor	Very slight	Precambrian	Lower	Continental		1	Trace
Soft	Poor	Slight	Late Precambrian	Middle	Fresh water	Pyrite	2	Very slow
Fairly hard	Fairly good	Fair	Paleozoic	Upper	Brackish water	Glauconite	3	Slow
Hard	Good	Medium	Mesozoic		Marine	Anhydrite	4	Medium
Very hard	Very good	High	Tertiary		Marine closed sea		5	Fast
		Very high	Pleistocene			Ironstone	6	Very fast
			Recent				7	Extremely fast
						Chert		

fossils, glauconite, dune sands, anhydrite, plant remains, etc.

The intermediate stages of deposition may be expressed by means of decimals, but, in general, the well cuttings do not provide evidence as to the finer points of sedimentation.

Porosity. For pure limestones or dolomites, the identity of which have been established by acid tests, a rough measure of the porosity would seem to be given by rapid specific gravity determinations made with the use of heavy liquids at closely spaced intervals from about 2.5 to 2.8. This is a tentative idea and has not been included in the general scheme. In the absence of these liquids a rather unsatisfactory series of numbers is applied to adjectives the meaning of which depends on the judgment of the examiner. This is for rapid routine work in which the nature of the material, or the time available, do not permit of the use of the more detailed and accurate methods.

Minerals. Only a few of the chief diagnostic minerals likely to be found in sediments and likely to be of value in locating contacts, have been given colors and corresponding numbers; these include pyrite, glauconite, chert, anhydrite, gypsum and coal (here included among the minerals). A capital letter is used for the name used as a noun, a small letter when used as a modifying adjective, thus, pyritic shale is py·5, glauconitic sandstone gl·2.

The use of the given series of numbers may seem rather confusing but the following conventions will help to simplify their use.

A definite succession of characters should be used, and a standard form should be in front of the operator as he is working.

The qualifying adjective should be separated from the name of the rock by a hyphen.

The parts of a compound adjective should be separated by periods, the groups of adjective by commas.

For example—dark greenish-grey pyritic sandy shale is 0.310, py-3; greenish-grey, very fine-grained glauconitic cal-

careous sandstone is 3.10, 1-gl.12; and very light greyish-brown, dense arenaceous dolomite is 30.16, 0–26.

The arrangement of the columns must be left to the discretion of the individual sample examiner but the following suggestions are offered.

The constituents that indicate marine conditions, such as foraminifera, crinoid fragments, belemnites etc., should be grouped together.

Constituents indicative of non-marine conditions, such as coal fragments, plant remains, carbonaceous shale, etc., should also be grouped together.

Between the two groups should be placed the group of columns which indicate a possible formation contact, such as pyrite, glauconite, phosphate, or beds of sand or pebbles, fossil detritus, etc.

The stratigraphic number column should be adjacent to the formation-contact column. With this arrangement the logical reason for placing a contact at a certain depth is at once apparent.

If characters other than color, grain size and lithology are recorded by the use of numbers, these numbers should be separated by a hyphen from the figure expressing lithology. No groups of more than three additional characters should be added unless they are separated by a hyphen.

In the plotting of a log the columns of numbers referring to one rock type and character should, as far as possible, be placed directly below each other, so that changes in color, grain size, lithology etc., can be rapidly picked out and correlated.

There are many additional characters of sediments that might be included in the color-numerical scheme. Some of these characters are: rapidity of disintegration in water; volume when wet; turbidity of supernatant liquid with time control; calcium carbonate content; ferrous and ferric iron content and their relationship; closely controlled specific gravity tests; organic content, proportions of phosphates and sulphates, insolubles, etc. But these would still further complicate a system which, it must be confessed, is very detailed.

In the above scheme also no provision has been made for the distinction between consolidated and unconsolidated clastic sediments. If desired, this distinction can be made by the use of a dash placed above and to the right of the sediment number and by the use of a darker color for the consolidated sediment. Thus, sand would be represented by 2-light yellow; sandstone by 2′-dark yellow; gravel by 1, light red; conglomerate by 1′, dark red.

In copying well logs the number system would probably save much time and space.

This article will have fulfilled its purpose only if it induces the knights of the sample, the microscope and the acid bottle to contribute their criticism and ideas to such an important subject as sample examination.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 16, NO. 3, P. 129
DECEMBER, 1946

ANNOUNCEMENT

GEOLOGY AS A PROFESSION

"The Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. now has for distribution at a price of ten cents, an excellent small booklet entitled "Geology as a Profession," Vocational Booklet No. 1, which is prepared by the National Roster of Scientific and Specialized Personnel. The author is Miss Ann R. Taylor working under the direction of Dr. W. T. Read, Chief of the Research Section, with the advice and assistance of many geologists. This booklet describes in about twenty pages the profession of geologists (not including geophysics). It gives the subdivisions of the geological profession, the working conditions and types of employment, the opportunities for women, the related fields of employment, beginning jobs, advancement and conditions of employment, postwar outlook in the profession, and the qualifications and training, and makes suggestions as to how to get a start. The booklet is attractively illustrated. It would be of special value to advisers of young students, and while written primarily from the employment point of view, would also give those entering the profession a condensed and business-like summary of what they might expect."

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 16, NO. 3, PP. 130–132
DECEMBER, 1946

REVIEWS

ZOBELL, C. E., 1946. *Marine Microbiology, A Monograph on Hydrobacteriology*, Vol. 17 of a New Series of Plant Science books, edited by Dr. Franz Verdoorn, managing editor of Chronica Botanica. Published by the Chronica Botanica Co., Waltham, Mass., G. E. Stechert and Co., New York, pp. i–xiv, 1–240. Price $5.00.

This work by Dr. ZoBell fills a long felt need and the standing of the author is a guarantee of its authority. There is a bibliography of over 750 titles. There is also an excellent index. A foreword is by Dr. Selman A. Waksman.

The scope of the book is probably best shown by the subjects considered in its eighteen chapters. These are as follows: General Introduction, The Marine Environment, Collection and Examination of Samples at Sea, Methods of Enumerating Marine Bacteria, Factors Influencing the Distribution of Bacteria in the Sea, Microorganisms in Bottom Deposits, Activities of Microorganisms in Bottom Deposits, Characteristics of Marine Bacteria, Aquatic Yeasts and Molds, Transformation of Organic Matter, The Nitrogen Cycle in the Sea, Bacteria Which Transform Sulphur Compounds, The Phosphorus Cycle, Relation of Marine Bacteria to Flora and Fauna, Microorganisms in Marine Air, Sanitary Aspects of Marine Microbiology, Economic Importance of Marine Microorganisms, and Microbiology of Inland Waters.

The book should be invaluable to students in many divisions of science and particularly so to limnologists, oceanographers, and sedimentationists. It has become increasingly obvious during the past quarter of century that microorganisms are important in the genesis of several varieties of sedimentary rocks. As stated in the foreword, "Marine bacteriology has become as much an essential branch of oceanography as have marine biology, marine geology, and physical and chemical oceanography." The book provides a place where sedimentationists and scientists in other fields may go to obtain authoritative data on bacterial activities.

W. H. TWENHOFEL

FANNING, L. M. and collaborators, 1945. *Our Oil Resources*. McGraw-Hill Book Company, New York, N. Y., pp. i–viii, 1–331. Price $4.00.

This book, prepared under the editorship of L. M. Fanning, consists of ten chapters, each written by a different author or authors, and presents an up-to-date analysis of the oil resources available to the United States together with information relating to methods of discovery, development, production, and refining. The chapters with their authors are as follows—

I. The role of private enterprise in the development of oil resources, John A. Brown, late President of the Socony-Vacuum Oil Co.

II. American oil companies in foreign petroleum operation, Eugene Holman, President, Standard Oil Co. of New Jersey.

III. Conservation of our oil and gas resources, J. C. Hunter, President, Mid-Continent Oil and Gas Association.

IV. Technology—the Great Multiplier. Exploration technology, O. D. Donnel, President, Ohio Oil Company and A. Jacobsen, President, Amerada Petroleum Company. Production technology, John M. Lovejoy, President, Seaboard Oil Co. of Delaware. Refining technology, Robt. E. Wilson, Chairman of the Board, Standard Oil Company of Indiana.

V. Our oil and natural gas reserves. The Earth's petroleum resources, Wallace Pratt, Vice-president, Standard Oil Company of New Jersey. Estimate of United States Oil Reserves, American Petroleum Institute. Our Natural Gas Resources, Lyon F. Terry, Second Vice-president, Chase National Bank, New

York. Cost of storage of military reserves of crude petroleum or products, F. W. Abrams, Vice-president, Standard Oil Co. of New Jersey.

VI. Our reserves of coal and shale, K. C. Heald, Chief Geologist, Gulf Oil Corporation, and Eugene Ayres, Chief Chemist, Gulf Research and Development Co.

VII. Oil from Coal and Shale, Robt. E. Wilson, Chairman of the Board, Standard Oil Co. of Indiana.

VIII. Oil in Public Domain, naval reserves and federal and state marginal lands. The Public Domain and naval reserves, W. H. Ferguson, Vice-president, Continental Oil Company. Lands of the United States, A. C. Mattei, President, Honolulu Oil Corp. Status of federal lands, L. T. Barrow, Vice-president, Humble Oil and Refining Co.

IX. Capital employed in the petroleum industry, J. E. Pogue, Vice-president, Chase National Bank and F. C. Coqueron, Petroleum Analyst, Chase National Bank.

X. The American oil industry, L. M. Fanning.

The standing of the several collaborators and the great fund of information available to them in the archives of their respective companies assures the reliability of what has been presented. The book is well written and very readable.

W. H. TWENHOFEL

ROSS, C. S. and HENDRICKS, S. B., 1945. *Minerals of the Montmorillonite Group, Their Origin and Relation to Soils and Clays.* Professional Paper 205-B, U. S. Geol. Surv., pp. i–iv, 23–79, 8 plates. Price $.35.

This paper presents a monographic study of the montmorillonite group of clay minerals. Some consideration is also given to the minerals of the kaolinite group. Clay minerals from 102 localities were analyzed. There is a bibliography of 304 titles.

The minerals of the montmorillonite group are montmorillonite, beidellite, nontronite, hectonite, and saponite. Other names have been proposed but the authors find them synonyms or not assignable to the montmorillonite group. The several minerals differ in composition and the functions of the composing atoms in the crystal lattice. Formulas of a special type are used to show composition and the base exchange possibilities. Analyses of the several minerals of the montmorillonite group are given in tables. Each mineral is described and a history of nomenclature is given. It was found that "mixed layer" minerals are not uncommon which consist of layers of minerals of the montmorillonite group interlayered with micas, chlorite, talc, brucite and possibly other minerals. Because of this fact and also to the entrance of many impurities in clay deposits, pure samples of the clay minerals are difficult to obtain.

Base exchange, an important property of the minerals of the montmorillonite group, is stated to be due to exchangeable cations on the surface of the silicate layers of the crystal structure and the quantities of these are determined by the excess negative charge within a layer. Base exchange capacities are given for 22 analyzed samples.

All clay minerals are constituents of soils and clays and montmorillonite is one of the most common of soil minerals. In areas of deep and long-continued weathering, as in the tropics and subtropics, and particularly where parent rocks are characterized by alkalic feldspars, kaolinite tends to form as the common clay mineral in association with high concentration of the sesquioxides of aluminum and iron. Montmorillonite and beidellite are common clay minerals in the soils forming in temperate and in many arid regions. The nature of the parent materials and the chemical environment are the fundamental factors which determine which clay minerals form.

Aside from the importance of study of the mineralogy of the clay minerals of

the montmorillonte group, the work is also very important to the study of sediments as the clay minerals are the most important constituents of soils, and soils, in turn, are the immediate sources of most of the mudstones (shales, claystones, and siltstones) which compose the greatest part of the sediments of the geologic column. Determination of the character of parent rocks and climatic conditions responsible for the formation of clay minerals brings somewhat nearer determination of the provenances responsible for the mudstones so abundantly present in the geologic column.

W. H. TWENHOFEL

Journal

of

Sedimentary Petrology

VOLUME 16

APRIL, 1946-DECEMBER, 1946

Nos. 1-3

W. H. TWENHOFEL, EDITOR

PUBLISHED BY THE

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

A DIVISION OF

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Box 979, Tulsa, Oklahoma

Journal of Sedimentary Petrology

INDEX TO VOLUME 16

Aberdeen, E., cited....19, 40
Absorption of Minnesota limestones and dolomites.... 75
Abyssal sediments.... 38
Agricultural Education Association, cited....21, 39
Alaskite, sediments derived from.... 121
Aletes.... 116
Allen, P., correction to article by.... 86
Allen, V. T., article by.... 52
Allen, V. T., cited.53, 54, 57, 58, 59, 62, 69, 71
American Society for Testing Materials, cited.... 9
Analyses of basalts.... 61
Analyses of basaltic clays.... 61
Analyses of Minnesota limestones and dolomites.... 84
Anatase.... 122
Andalusite.... 122
Augite.... 59
Baker, C. L., cited.... 18
Basaltic clays, analyses of.... 61
Basalts, analyses of.... 61
Baturin, D. J., cited....31, 39
Beach Erosion Board, cited....45, 51
Beach sands, textural changes of.... 43
Beaches, sediments of.... 37
Beidellite-nontronite....53, 55, 56, 57, 58
Bentall, R., cited....116, 120
Biotite.... 94
Bottom samples of Neder-Rijn, Holland....27, 28
Bradley, R. S., cited....69, 71
Bradley, W. H., cited....112, 120
Branaugh, R. L., article by.... 15
Bray, R. H., cited....67, 71
Breccia, weathered.... 56
Brezesinska-Smithuysen, W. C., cited.. 39
Bryan, K., cited....45, 51
Cady, J. G., cited.... 95
Cambrian fossils of the Grand Canyon Region.... 87
Cambrian history of the Grand Canyon Region.... 87
Cape Ann, Mass....44, 45
Capitan Mountain, N. Mex.... 121
Capitan Peak, N. Mex.... 121
Carlisle shale.... 122
Carlsbad, N. Mex.... 14
Carnallite.... 14
Carroll, D., cited.... 95
Castle Neck, Mass.... 44
Castle Rock, Wash....52, 53, 55
Chehalis, Oregon.... 58
Chehalis, Oregon, weathered gravel at.. 57
Cheltenham fire clay, Mo.....63, 64, 66, 68
Cherokee Mine, Calif.... 58
Chesapeake Bay.... 47
Chloritoid, weathering of.... 94
Clackamas County, Oregon.... 53
Clatskanie Quadrangle, Wash.... 58
Clay minerals, conditions determining formation of.... 59
Coal balls.... 116
Coefficient of sorting....45, 46
Coffins Beach, Mass....43, 44, 45
Color-numerical system applied to well logs.... 124
Color-numerical system for sediments.. 124
Colorado School of Mines, announcement by.... 86
Columbia Plateau.... 60
Composition of Minnesota limestones and dolomites.... 84
Comparative rates of weathering of some common heavy minerals.... 91
Conditions determining formation of different kinds of clay minerals... 59
Correlation by spores and pollen.110, 111, 117
Cowlitz County, Oregon....52, 57
Cumulative curves.... .....23, 24, 25, 26, 27, 28, 29, 30
Cuthbert, F. L., cited....70, 71
Daly, R. A., cited....60, 62
Dawson, Sir W., cited.... 112
Diagenesis.... 70
Dockum B ds.... 121
Doeglas, D. J., article by.... 19
Doeglas, D. J., cited....19, 39, 92, 95
Dohm, C. F., cited.... 40
Dolomites of southeastern Minnesota.. 72
Dryden, C., article by.... 91
Dryden, C., cited....94, 95
Dryden, L., article by.... 91
Dryden, L., cited....94, 95
Dune sands.... 26
Duxbury Beach, Mass.... 50
East-Indies, sediments of adjacent waters.... 87
Edelman, C. H., cited....92, 95
Erdtman, G., cited....113, 117, 120
Eutalla, Wash.... 57
Excelsior (Wash.) high-alumina clay...59, 60
Experimental error.... 3
Ewell, R. H., cited....59, 62
Fanning, L. M., review of book by.... 130
Feldspars.... 55
Feldspars from alaskite.... 122
Fern Ridge, Oregon.... 58
Field error.... 3
Fisher, R. A., cited.... 9
Fluviatile clays.... 29
Fry, W. H., cited....70, 71
Galena limestone, Minn....72, 74, 80
properties of.... 82
Galpin, S. L., cited.... 69
Garnet, weathering of.... 92
Geology as a profession, announcement of.... 129
George, W. O., cited.... 18
Gibbsite, Colorado....53, 54, 55
Golden-Morrison area, announcement of report on.... 86
Goldich, S. S., cited.... 9, 95
Grade limits, choice of.... 21
Grand Canyon, fossils of.... 87

Grand Canyon Region, Cambrian history of 87
Gravels (weathered), analyses of 61
Greaves-Walker, A. F., cited 69, 71
Green River shale 112, 120
Green River oil shale 64, 67
Grim, R. E., cited 67, 69, 71
Gry, H., cited 40
Halloysite-kaolinite 55, 56, 57, 58
Hand sieving 8
Harker, A., cited 71
Hasemen, J. F., cited 95, 96
Heavy minerals, comparative rates of weathering 91
Heavy minerals of the Wissahickon schist 91, 92
Hendricks, S. B., cited 70, 71
review of book by 131
High-alumina clays 52, 59, 60
Histograms 20, 21
Histograms of spores and pollen 119
Histograms of weathering of minerals .. 93
Hjulström, F., cited 40
Hodson, F., cited 69, 71
Hopkins, T. C., cited 69
Hornblende from alaskite 122
Hornblende, weathering of 92
Hosking, J. S. 59, 62
Hydrobacteriology 130
Hypersthene, weathering of 94
Ibrahim, A. C., cited 116, 120
Iddingsite 56, 57, 58, 59
Ilmenite 57
Insley, H., cited 59, 62
Insoluble residues in Minnesota limestones and dolomites 78
Ipsworth Beach, Mass. 43, 44, 45
Jeffries, C. D., cited 95
Jordan sandstone 72, 73
Kaolinite 53, 54
Kaolinite-halloysite 56
Kaolinization 59
Keller, W. D., article by 63
Kerr, P. F., cited 69, 71
King, R. H., article by 14
Knox, E. M., cited 118, 120
Krumbein, W. C., cited 9, 19, 40
Kuenen, P. H., review of report by 87
Kyanite, weathering of 94
Laboratory error 3
Lagonda shale (Mo.) 63, 64, 67
Lake Erie 47
Lake sediments 37
Lathram, R. H., article by 72
Leighton, M. M., cited 59, 62
LeRoy, L. W., announcement of report by 86
Lesley, J. P., cited 69
Lever, M. N., cited 3
Limonite 55
Lindgren, W., cited 58, 62
Limestones of southeastern Minnesota . 72
Loess deposits 35
Logan Hill, Wash. 57
Long Island, N. Y. 47
Longnecker, O. M., cited 18
Love, S. K., cited 109
Lovejoy, E., cited 69, 71
MacCarthy, G. R., cited 47, 51
MacClintock, P., cited 59, 62
Maceration of sedimentary rocks 112
Maddox, D. C., article by 124
Magnetite from alaskite 122
Mankato, Minn. 72
Marine delta sediments 37
Marine microbiology 130
Marion County, Oregon 58
Marshall, C. A., cited 95, 96
Marshall, P., cited 50, 51
Martens, J. H. C., cited 95, 96
Massachusetts Bay 50
Mayger, Wash. 58
McKee, E. D., review of article by 87
McKitrick, W. E., cited 58
McQueen, H. S., cited 69, 71
Mechanical analysis 19, 45
Median diameters 45, 46, 47, 48, 49
Megaspores 111
Microspores 111
Merrimac River 44, 45
Miller, B. K., cited 69, 71
Millott, J. O'N. 110, 120
Minnesota dolomites, composition of .. 84
Minnesota limestones, composition of .. 84
Miser, H. D., cited 58, 62
Mohr, E. C., cited 31, 40
Molalla, Oregon 53, 54, 55, 58
Molalla River, Oregon 54, 55
Monazite, weathering of 94
Monoletes 116
Montmorillonite 53, 54, 55
Montmorillonite group of minerals 131
Mud cracks 21
Neritic sediments 38
Netherlands East-Indies, report of sediments of 87
New Zealand beach 50
Nichols, R. L., article by 52
Nichols, R. L., cited 52, 53, 54
Niggli, P., cited 19, 40
Noll, W., cited 59, 62
North Texas, volcanic sediments of 15
Nontronite 59
Nontronite-beidellite 53, 59
Oil resources of the United States 130
Oneota dolomite 72, 73
Oneota dolomite, properties of 77, 79
Oroville, Calif. 58
Otto, G. H., cited 9
Olivine 57
Olivine basalt (weathered) 56, 57
Patton, L., cited 121
Pettijohn, F. G., cited 47, 51
Péwé, T. L., article by 97
Phi arithmetical mean 4
Phi mean 5, 6
Phi skewness 4, 5
Phi standard deviation 4, 5
Plant microfossils, collection of 112
Plant microfossils, methods of study ... 112
Plant microfossils, occurrence of 112
Platteville limestone 72, 74, 82
Plum Island, Mass. 43, 44, 45, 46
Pollen, use in correlation 110
Pollen, types of 110
Porphyry (weathered) 56
Potonie, R., cited 116, 120
Pumicite 15, 16

Quartz 55
Quartz from alaskite 122
Quartiles 45, 46
Raccoon River, Iowa 104, 105
Raistrick, A., cited 111, 114, 116, 118, 120
Raymond, P. E., cited 50
Reed, L. C., cited 18
Resser, C. E., review of article by 87
River sediments 27, 35, 36
Rook Creek, Illinois 104
Rock Island sampler of the U. S. Army Engineers 98, 100, 101
Root Valley sandstone 72, 73
Ross, C. S., cited 57, 58, 62, 69, 71
Ross, C. S., review of book by 131
Ross, D. W., cited 69
Rowland, R. A., cited 69, 71
Salt clay, mud cracks in 14
Sampler, time-integrating 98
Schalk, M., article by 43
Schalk, M., cited 51
Schied, V. E., cited 57, 59, 62
Schoff, J. M., cited 116, 120
Schultze's solution 114
Sedimentation balance 22
Sediments of beaches 37
Sediments of lakes 37
Sediments of marine deltas 3
Sellards, E. H., cited 18
Shaker error 3
Shakopee dolomite 73
Shakopee dolomite, properties of 80, 81
Shakopee, Minn. 73, 80
Shannon, E. V., cited 57, 62
Shrock, R. R., cited 58, 62
Sidwell, R., article by 15, 121
Sieve shakers, comparison of 3
Sieve shakers, description of 4
Sillimanite, weathering of 94
Simpson, J., cited 118, 120
Skewness 45, 46, 48, 49
Smith, G. E., cited 62
Smith, R. M., cited 71
Snedecor, G. W., cited 10
Snellius Expedition to Netherlands East-Indies 87
Sorting 45, 47, 48, 49
Specific gravity of Minnesota limestes and dolomites 76
Splitting error 3
Spokane County, Wash. 59
Staurolite from alaskite 122
Staurolite, weathering of 92
Stephenson, L. W., cited 58, 62
Stevenson, J. J., cited 69
Stetson, H. C. 50
Stokes formula 23
Stout, W., cited 69
Stow, M. H., cited 95, 96
Straub, L. G., cited 31, 40
Stream samples of sediments 27, 28, 29, 30, 31, 32, 33, 34
Strength of Minnesota limestones and dolomites 76
Sublimity, Oregon 58
Sudry, L., cited 40
Suspended detritus 30, 31
Suspended sediment program of U. S. Army Engineers, Rock Island, Ill., office 97
Swineford, A., article by 3
Swineford, F., article by 3
Tidal flat clays 29
Tidal flat deposits 26, 27
Time error 3
Timmermans, P. D., cited 40
Textural changes in beach sands 43
Thiel, G. A., article by 72
Thoulet, J., cited 40
Time-integrating sampler 98
Tourmaline, wrathering of 94
Trask, P. D., cited 19, 40
Treasher, R. C., cited 52, 55, 58, 62
Triletes 116
Twenhofel, W. H., reviews by 87, 88, 130, 131, 132
Udden, J. A., cited 70, 71
U. S. Army Engineers, suspended sediments program of Rock Island Office 97
Veen, J., van, cited 20, 40
Volcanic ash 15
Volcanic sediments of north Texas 15
Weathered breccia 56
Weathered gravels of Oregon and Washington 52
Weathered sands of Oregon and Washington 52
Weathered porphyry 56
Weathering of heavy minerals, comparative rates of 91
Weaver, C. E., cited 53, 62
Well logs, color-numerical system applied to 124
Wentworth, C. K., cited 10, 19, 40
Wheeler, H. A., cited 69
White, J. W., cited 95
Wilder, B., cited 54
Wilson, H., cited 52, 55, 58, 62
Wilson, L. R., article by 116
Wilson, L. R., cited 116, 120
Witham of Lartington, cited 112, 120
Wodehouse, R. P., cited 112, 116
Worthen, A. S., cited 69
Yakima basalt 60
Zircon, weathering of 92
ZoBell, C. E., review of book by 130
Zuur, A. J., cited 40

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

SOCIETY OFFICERS (MARCH, 1946-MARCH, 1947)

President: F. W. ROLSHAUSEN, Humble Oil and Refining Company, 1068 Humble Building, Houston 2, Texas

First Past-President: JOHN R. SANDIDGE, Magnolia Petroleum Company, 1704 Alamo National Building, San Antonio, Texas

Second Past-President: DONALD D. HUGHES, Box 1334, Stanford University, California

Vice-President: CECIL G. LALICKER, Department of Geology, University of Oklahoma, Norman, Oklahoma

Secretary-Treasurer: H. B. STENZEL, Bureau of Economic Geology, University of Texas, Austin, Texas

---

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

ASSOCIATION OFFICERS (MARCH, 1946-MARCH, 1947)

President: EARL B. NOBLE, Union Oil Company of California, 1100 Union Oil Building, Los Angeles 14, California

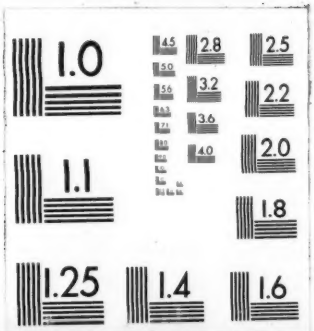
Past-President: M. G. CHENEY, Anzac Oil Corporation, Coleman, Texas

Vice-President: D. PERRY OLCOTT, Humble Oil and Refining Company, Box 2180, Houston, Texas

Secretary-Treasurer: EDWARD A. KOESTER, Darby & Bothwell, Inc., 612 Orpheum Building, Wichita, Kansas

Editor: GAYLE SCOTT, Department of Geology, Texas Christian University, Fort Worth, Texas

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN


1.0
1.1
1.25
1.4
1.6
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.8